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CURRENT RESEARCH PART H
FRONTIER GEOSCIENCE PROGRAM,
QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

RECHERCHES EN COURS PARTIE H
PROGRAMME GÉOSCIENTIFIQUE DES RÉGIONS PIONNIÈRES,
ÎLES DE LA REINE-CHARLOTTE, COLOMBIE-BRITANNIQUE

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CURRENT RESEARCH, PART H
FRONTIER GEOSCIENCE PROGRAM, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

RECHERCHES EN COURS, PARTIE H
PROGRAMME GÉOSCIENTIFIQUE DES RÉGIONS PIONNIÈRES, ÎLES DE LA REINE-CHARLOTTE, COLOMBIE-BRITANNIQUE

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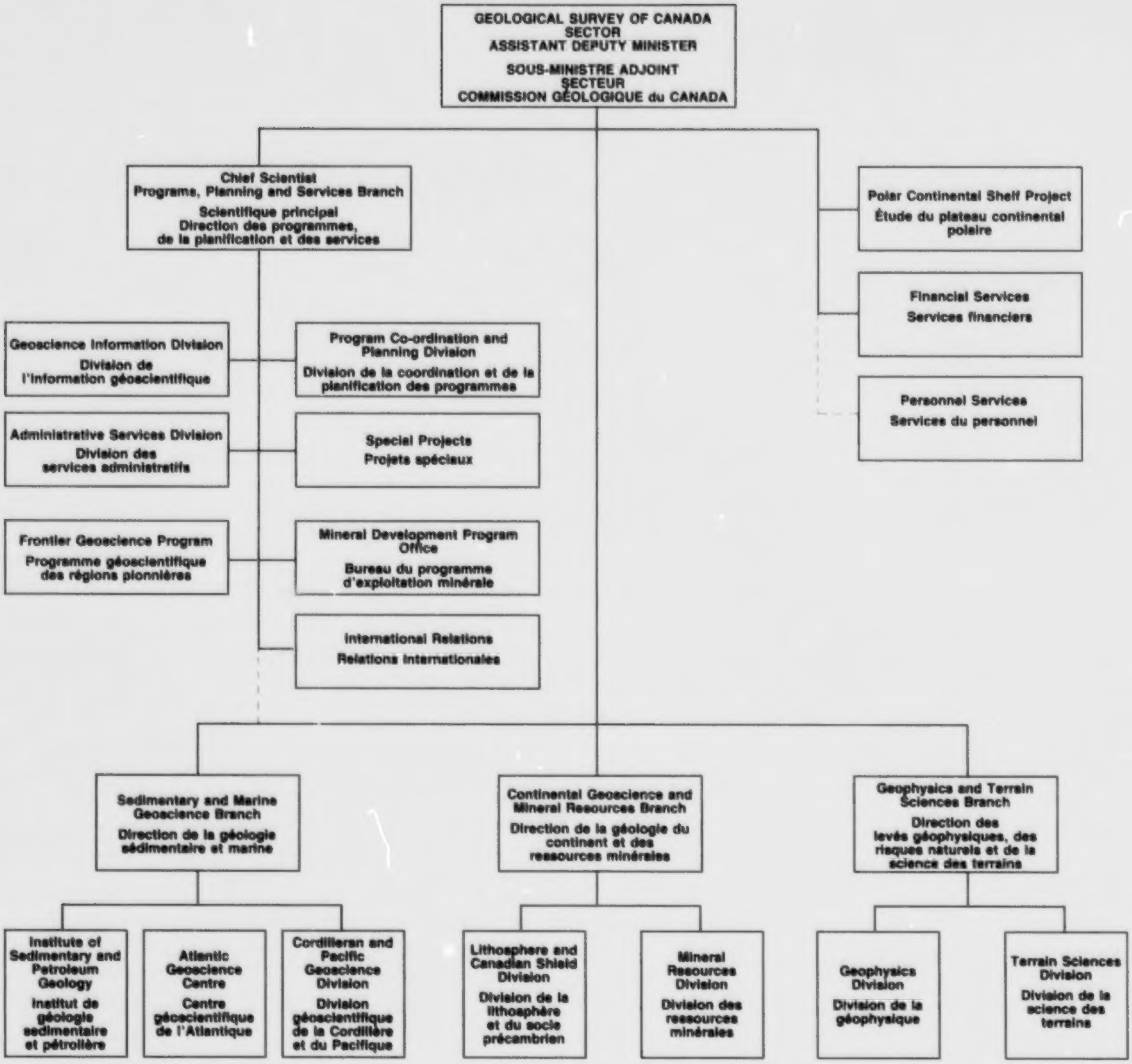
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Update on the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia

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Cordilleran and Pacific Geoscience Division, Vancouver

Thompson, R.I., Update on the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 1-2, 1989

The Queen Charlotte Frontier Geoscience Program (QCFGP) is on time and on budget. Our primary objective is to produce a compilation of results in 1989. The report will contain an extensive and current database, complimented by summary interpretations.

Significant progress continues on all fronts. The reflection and refraction experiments were completed successfully; data processing is in progress and we look forward to initial interpretations of deep basin structure as well as a better understanding of the geometry and extent of structures in Cretaceous and Tertiary strata. Our understanding of onland geology continues to expand; we have a better appreciation of the styles and timing of deformation, and we are beginning to understand how structures influenced stratigraphic evolution. Heatflow measurements, dyke and pluton studies, vitrinite reflectance measurements, and conodont colour alteration measurements, provide a comprehensive database for the evaluation of thermal history; reassessment of vitrinite reflectance values on cuttings from offshore wells is about to commence. In places, basal beds of the Cretaceous Haida Formation are a good potential reservoir; efforts are now focused on relating this to structural and stratigraphic features and projecting them offshore. Onshore exposures of the Tertiary Skonun Formation have been examined in detail and new sedimentological interpretations presented. Hazards to development, such as shallow gas, recent faulting, and unstable slopes, are being evaluated on a regional basis using shallow seismic techniques in combination with sidescan sonar surveys; geotechnical properties of seafloor sediments are being measured to further assess slope stability in the event of an earthquake.

The program has evoked interest from many Queen Charlotte Islands residents; concern has been expressed by the Haida, the Islands Protection Society, the Earth Life

Mis à jour du Programme géoscientifique des régions pionnières, îles de la Reine-Charlotte, Colombie-Britannique

R.I. Thompson
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Thompson R.I., Mis à jour du Programme géoscientifique des régions pionnières, îles de la Reine-Charlotte, Colombie-Britannique; dans Recherche en cours, partie H, Commission géologique du Canada, Étude 89-1H, p. 1-2, 1989.

Le Programme géoscientifique de la région pionnière de la Reine-Charlotte se déroule dans le respect de l'échéancier et du budget. L'objectif premier est de produire une compilation des résultats en avril 1989. Le rapport comprendra une base étendue de données à jour complétée par des interprétations sommaires.

Des progrès importants sont accomplis sur tous les fronts. Les expériences de réflexion et de réfraction ont été complétées avec succès; le traitement des données est en cours et permettra des interprétations initiales de la structure des bassins profonds tout en assurant une meilleure connaissance de la géométrie et de l'étendue des structures des couches du Crétacé et du Tertiaire. La connaissance de la géologie continentale progresse; les styles et la chronologie de la déformation sont mieux saisis et l'on commence à comprendre comment les structures ont influencé l'évolution stratigraphique. Les mesures du flux de chaleur, les études de dykes et de plutons, les mesures de la réflectance de la vitrinite et de l'altération de la couleur des conodontes constituent une base étendue de données pour l'évaluation des antécédents thermiques; une réévaluation des valeurs de réflectance de la vitrinite dans les déblais de forage de puits au large des côtes est sur le point de débuter. Par endroits les couches de base de la formation crétacée d'Haida constituent de bons réservoirs potentiels; les efforts sont maintenant centrés sur la mise en relation de ces connaissances avec les entités structurales et stratigraphiques et le prolongement de ces dernières en direction du large. Les affleurements sur le rivage de la formation tertiaire de Skonun ont été examinés de manière détaillée et de nouvelles interprétations sédimentologiques ont été présentées. Les dangers pour la mise en valeur, comme la présence de gaz à faible profondeur, la formation récente de failles et des pentes instables, sont évalués sur une base régionale par des méthodes

Canada Foundation, and local fishermen over potential harm that might come from offshore seismic reflection studies. We are sensitive to these concerns and funded a regional survey of planktonic species as the first step toward establishing a reliable database showing the density and type of lifeforms in the upper part of the water column. We are grateful to the Department of Fisheries and Oceans for managing this study. Concern for the environment continues to be part of the Frontier Geoscience Program mandate; to that end we monitor seismic activity on a continuing basis to better assess what effect earthquakes might have on seabed stability.

sismiques à faible profondeur combinées à des levés au sonar à balayage latéral; les propriétés géochimiques des sédiments du fond marin sont mesurées afin de mieux évaluer la stabilité des pentes en cas de séisme.

Le programme a suscité un intérêt chez un grand nombre des résidents des îles de la Reine-Charlotte; les Indiens Haida, la « Islands Protection Society », la « Earth Life Canada Foundation » et des pêcheurs locaux ont exprimé leur inquiétude quant aux effets nuisibles des études de sismique réflexion en haute mer. Nous sommes sensibilisés à ces préoccupations et nous avons financé un relevé régional des espèces planctoniques à titre de première étape de l'établissement d'une base de données fiables montrant la densité et la diversité des formes de vie dans la partie supérieure de la colonne d'eau. Nous exprimons nos remerciements au ministère de Pêches et Océans pour la gestion de cette étude. Un intérêt pour l'environnement reste intégré au Programme des régions pionnières; à cette fin l'activité sismique est surveillée de manière continue pour mieux évaluer l'effet que pourraient avoir des séismes sur la stabilité du fond marin.

Seismic reflection and refraction experiment in the Queen Charlotte Basin, British Columbia[1]

K.M.M. Rohr, G. Spence, I. Asudeh[2], R. Ellis[3], and R. Clowes[3]
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Rohr, K.M.M., Spence, G., Asudeh, I., Ellis, R., and Clowes, R., Seismic reflection and refraction experiment in the Queen Charlotte Basin, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 3-5, 1989.

Abstract

Eleven hundred kilometres of seismic reflection and refraction data were collected from eight lines in the Queen Charlotte Basin. Data were recorded for 14 seconds at a sample rate of 4 ms; shot spacing of 45 m resulted in 40-fold data. Over 90 000 seismograms were recorded by seismometers placed on the Queen Charlotte Islands and the mainland; arrivals were detected at distances as much as 120 km. Processing and interpretation of the data are in progress.

Résumé

Des données de sismique réflexion ont été recueillies le long de neuf lignes sur mille cent kilomètres dans le bassin de la Reine-Charlotte. Les données étaient enregistrées pendant 14 secondes à un taux d'échantillonnage de 4 ms; les tirs étaient espacés de 45 m et ont produit des données suivant une couverture de 40 plis. Plus de 90 000 sismogrammes ont été enregistrés par des sismomètres placés dans les îles Reine-Charlotte; les premières ondes ont été captées à une distance aussi éloignée que 120 km. Le traitement et l'interprétation des données sont en cours.

---

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As part of the Frontier Geoscience Program in the Queen Charlotte Basin a seismic experiment was undertaken in July 1988 (Fig. 1). It was a reconnaissance survey designed to map the structural style of the sedimentary basin, to identify major crustal structures, and to use these features to interpret the tectonic history of the region.

The Queen Charlotte Basin was explored in the early 1970s and eight wells were drilled offshore. Up to 5000 m of sediments were drilled; basement is not always easily observed in the old seismic data. Sediments are 5 Ma old and younger in Hecate Strait which was thought by Yorath and Hyndman (1983) to have formed by plate flexure caused by oblique strike-slip faulting. In Queen Charlotte Sound sediments as old as 15 Ma were drilled; according to Yorath and Hyndman (1983) these may have been deposited during rifting as the Anahim hot spot passed by. Our seismic lines were placed over the old wellsites to allow correlation of reflectors with drilled units. Line 7 was extended north to cross a prominent magnetic anomaly and line 3 was placed over a large gravity anomaly on the continental shelf. Line 9 was shot for free while the ship was in transit and should elucidate structure of the active spreading centre offshore.

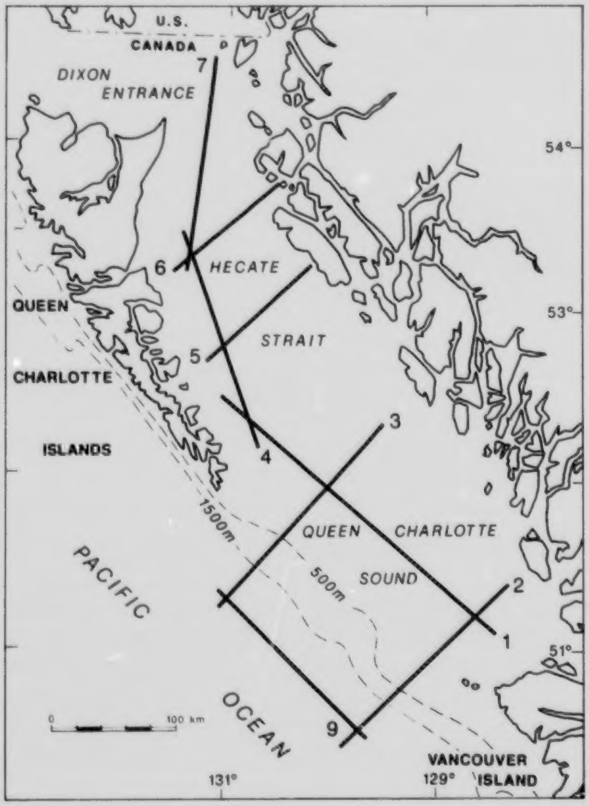

Figure 1. Location of seismic lines in Queen Charlotte Basin.

Seismic reflection data were collected to delineate structure; refraction data were collected simultaneously to measure seismic velocities and structure. These data combined with other studies in the region will provide insight into the architecture and history of the basin. The purpose of this paper is to describe the field operations and give a brief description of the data-set and the status of data analysis.

Eleven hundred kilometres of seismic reflection data were collected in two and a half weeks. Geophysical Services Inc. of Calgary (GSI) was the contractor; we used their Canadian vessel, the *Edward O. Vetter*. Navigation with Loran C was shaky to start with; but improved once a new receiver was obtained. Transit satellites and GPS were used whenever possible for more accurate positions. Tidal currents created noise on hydrophones near the boat and made the streamer feather, i.e. travel at an angle to the vessel. Slowing the boat down to 3.5 or 4.0 knots reduced noise, which can be further dealt with during processing.

The specifications for shooting were designed to image the deep crustal structure as well as the upper sedimentary units. We used a tuned 6400 cubic inch array of 64 airguns which were towed at a depth of 12 m in an 80m-wide configuration. The streamer was 3600 m long and consisted of 240 digital groups, each 15 m long. Ten birds or levellers with compasses were placed along the streamer; they kept the streamer within a metre of its desired depth of 12 m. Data were recorded for 14 s at a sample rate of 4 ms; shot spacing of 45 m resulted in 40-fold data.

Data processing is underway at GSI in Calgary. Shotpoints have been f-k filtered to attenuate water-born noise; brute stacks have been made for all lines. Signature and spiking deconvolution have been applied to compress the source wavelet and attenuate water multiples; velocity analyses are underway. The brute stacks show good arrivals from the sedimentary section, basement, the lower crust, and Moho.

Refractions and wide-angle reflections from the airgun shots were recorded on land seismographs distributed around Hecate Strait and Queen Charlotte Sound (Fig. 1). The Lithoprobe digital seismographs provided by Geophysics Division, Ottawa were deployed at eleven sites, and FM analog systems from the University of British Columbia recorded arrivals at 9 sites. Each airgun line was recorded at one digital and one analog site off the landward ends of the line and at nearby offline or broadside sites. The shot trigger system on board the *Vetter* was tied into a GOES satellite receiver clock so that absolute shot times could be determined. Up to 10% of the shot times were not recorded due to equipment problems; the missing times will be interpolated based on an alignment of refracted arrivals.

Fifty-one digital seismographs were available for the project. They recorded 1 Hz geophones at 120 samples per second storing 1 Mbyte or 1.2 hours of data in their solid state memory. Instruments recorded 40 second windows separated by 40 second gaps; this effectively doubled the elapsed time covered. As a special experiment, line 6 at its western end was recorded continuously. Arrivals out to 30 km were also recorded using radio telemetered sonobuoys at two sites: the northern end of line 2 and the western end of line 6. The signal was received on board the ship and was recorded digitally. Delays in starting the work crippled the OBS portion of the experiment which finally died when 7 of 8 instruments failed to return to the surface.

Processing of the refraction data entails digitization of the data recorded on the UBC instruments, determination of missing shot times and translation of digital data to SEGY format. Once digital data are available, band pass filtering and binning the data can be done. Replays of some of the data show that arrivals as far as 200 km away were recorded by the seismographs.

To summarize, we successfully completed a major seismic experiment in the Queen Charlotte Basin. Eleven hundred kilometres of multi-channel seismic reflection data were collected while seismometers on land recorded all lines for a total of over 90 000 seismograms. Our first glimpses of the data are encouraging; interpretation and integration with other data sets in the region are underway.

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Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Regional mapping update, central Queen Charlotte Islands, British Columbia[1]

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Thompson, R.I. and Thorkelson, D., Regional mapping update, central Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 7-11, 1989.

Abstract

Two fold episodes have been identified. The first occurred prior to, or during, the start of Middle Jurassic Yakoun volcanism; the second occurred in Late Cretaceous or early Tertiary, after deposition of Upper Cretaceous Honna conglomerate. Block faults were active from Middle Jurassic until late Tertiary.

Neither the Rennell Sound fold belt nor the northern strands of the Louscoone Inlet Fault were zones of significant, right-lateral, strike-slip displacement during Tertiary time.

The southwestern side of the Rennell Sound fold belt contains slices of Triassic Karmutsen volcanics imbricated with limestone and siltstone of the Kunga Group (Upper Triassic and Lower Jurassic). The belt crosses Louise and Moresby islands and does not support a simple, west-side-up, flexural model for Tertiary evolution of Hecate Strait.

The eastern side of the Rennell Sound fold belt parallels an older block fault. The largest and tightest Late Cretaceous and/or Tertiary folds were, in part, controlled by pre-existing block faults.

Résumé

Deux épisodes de plissement ont été identifiés. Le premier s'est déroulé avant, ou pendant, le début du volcanisme ayant produit la formation de Yakoun au Jurassique moyen; le deuxième est survenu pendant la fin du Crétacé ou le début du Tertiaire, après le dépôt du conglomérat de la formation d'Honna au Crétacé supérieur. Des blocs faillés étaient actifs du Jurassique moyen jusqu'à la fin du Tertiaire.

Ni la zone orogénique de la baie Rennel, ni les extrémités septentrionales de la faille du bras Luscoone n'étaient des zones de décrochement latéral dextre important pendant le Tertiaire.

Le côté sud-ouest de la zone de plissement de la baie Rennel renferme des lames de roches volcaniques triassiques du groupe de Karmutsen imbriquées de calcaires et d'aleurolites du groupe de Kunga (Trias supérieur et Jurassique inférieur). La zone traverse les îles Moresby et Louise et ne corrobore pas un modèle de plissement simple avec le côté ouest dirigé vers le haut pour l'évolution du détroit d'Hécate au Tertiaire.

Le côté oriental de la zone de plissement de la baie de Rennel est parallèle à un bloc faillé plus ancien. Les plus grands et les plus serrés des plis de la fin du Crétacé et du Tertiaire, ou des deux époques, étaient en partie contrôlés par des blocs faillés pré-existants.

---

[1] Contribution to Frontier Geoscience Program

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INTRODUCTION

Detailed geological mapping was extended southward, beyond the limits of 1987 work (Thompson, 1988) to include the Cumshewa Inlet area, northern and western Louise Island, and the area near Lagoon and Sewell inlets (Fig. 1, 2). Compilation of results from 1987 and 1988 field seasons is nearing completion; maps will be published at 1:50 000 scale together with cross-section interpretations, and derivatives such as structure contour and isopach maps.

This program was begun for three reasons: 1) to apply the excellent biostratigraphic data base that continues to be refined; 2) to construct detailed geometrical interpretations and assess whether, in similar geological circumstances, stratigraphic and or structural hydrocarbon traps could be expected in the offshore, beneath Hecate Strait; and 3) to test and improve (or replace) existing interpretations of Queen Charlotte geological history. We have covered a small area despite six months of field work. But the new, more constrained map patterns are contributing to geological interpretations significantly different from those previously published (e.g. Yorath and Chase, 1981; Yorath and Hyndman, 1983; Yorath, 1988).

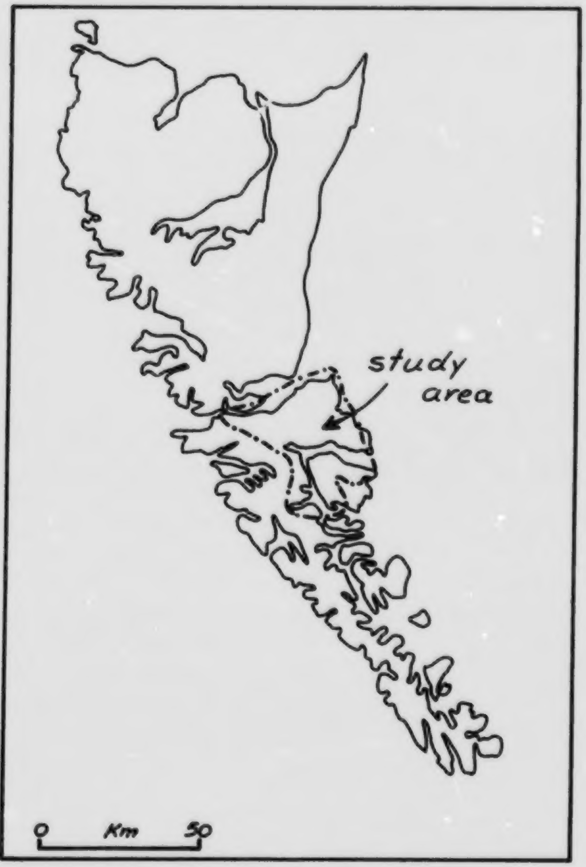

Figure 1. Location map showing extent of new mapping (within dashed line) on northern Moresby Island.

The mapping program combines two approaches: Thompson is responsible for continuity and regional coverage; Lewis (Ph.D. Candidate, University of British Columbia) has focused on the geometry and kinematics of structural development through detailed mapping and analysis of key areas (Lewis and Ross, 1988, 1989). The mapping program expanded in 1988 when J. Hesthammer and J. Indrelid (M.Sc. candidates, University of British Columbia) began detailed mapping and structural analysis of central Graham Island (Hesthammer and Indrelid, 1989).

Higgs (1988) published a summary of the tectonic setting and structure of the Queen Charlotte Islands without incorporating any of the data or interpretations this program has to offer (published and unpublished material were available at the time of writing). We think our results are significant, and refer readers to other papers in this volume as well as Lewis and Ross (1988) and Thompson (1988).

LACK OF EVIDENCE FOR TERTIARY STRIKE-SLIP: NORTHERN MORESBY ISLAND

We offer four conclusions regarding the Rennell Sound and Louscoone Inlet faults (Sutherland Brown, 1968; Yorath and Hyndman, 1983): 1) The Rennell Sound fault system is a fold and fault belt along which there was little or no right-lateral strike-slip displacement during Tertiary or earlier time; 2) there is no evidence for significant right-lateral strike-slip along either northern strand of the Louscoone Inlet Fault; 3) the Louscoone Inlet Fault is not the offset, southern extension of the Sandspit Fault; and therefore 4) structural linkage during the Late Oligocene and Miocene between the Rennell Sound fold belt, Louscoone Inlet Fault and extending crust beneath Queen Charlotte Sound, is not substantiated on land.

The model for Tertiary opening of Queen Charlotte Sound, put forward by Yorath and Hyndman (1983), Yorath (1988) and recently embraced by Higgs (1988), requires significant (greater than 50 km) right-lateral strike-slip displacement along the Louscoone Inlet Fault, followed by right-lateral displacement along the Rennell Sound Fault. Fieldwork in 1987 showed that stratigraphic contacts between Cretaceous map units (Longarm Formation and Honna Formation) could be traced, uninterrupted, across each strand of the Rennell Sound Fault as mapped by Sutherland Brown (1968) — Tertiary strike-slip displacement was not supported (Fig. 2). The Rennell Sound Fault was renamed the Rennell Sound fold belt (Thompson, 1988) in recognition of the steep bed dips and tight folds that occur along this trend. Fieldwork on northern Louise Island during 1988 demonstrated that the Rennell Sound fold belt can be traced without interruption to the eastern shore of Louise Island (Fig. 2). This negates the possibility of significant strike-slip along either northern strand of the Louscoone Inlet Fault during the Tertiary. Anderson (1988, p. 12) working farther south, suggested that mineral fabrics attributed to the Louscoone Inlet fault '...appear to be closely associated with external and interphase internal intrusive contacts and is interpreted as synintrusive rather than as syntectonic as suggested by Sutherland Brown (1968).' (see also Anderson and Greig, 1989).

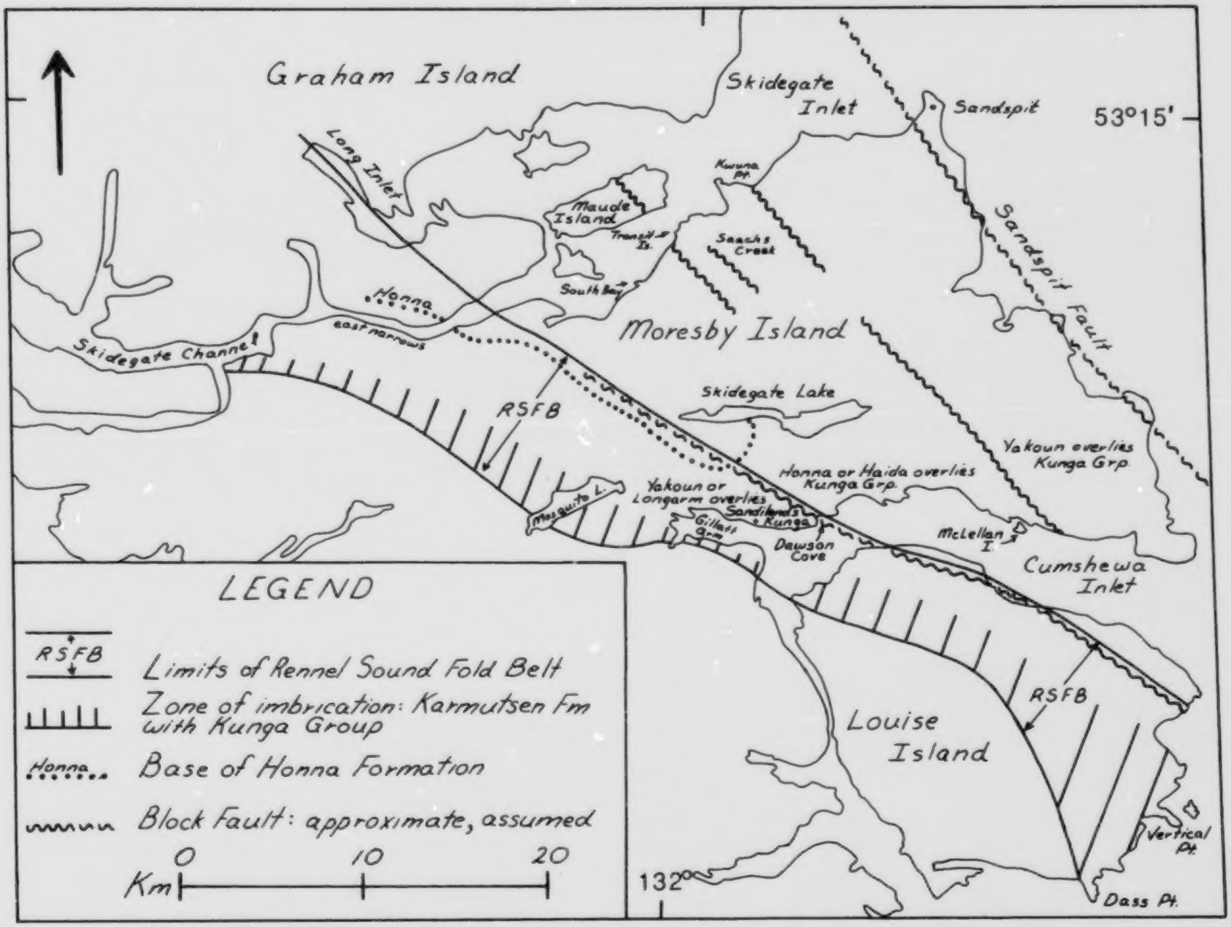
Graham Island
Skidegate Inlet
Sandspit
53°15'
Long Inlet
Maude Island
Transit Is.
South Bay
Kwuna Pt.
Sachs Creek
Sandspit Fault
Honna
east narrows
Skidegate Channel
Moresby Island
Skidegate Lake
RSFB
Yakoun overlies Kunga Grp.
Honna or Haida overlies Kunga Grp.
Yakoun or Longarm overlies Sandilands & Kunga
Mosquito L.
Gillatt Arm
Dawson Cove
McLellan I.
Cumshewa Inlet
Louise Island
RSFB
Vertical Pt.
Dass Pt.
132°
LEGEND
RSFB Limits of Rennel Sound Fold Belt
Zone of imbrication: Karmutsen Fm with Kunga Group
Honna Base of Honna Formation
Block Fault: approximate, assumed
0
10
20
Km

Figure 2. Sketch map of Northern Moresby Island showing the extent of the Rennell Sound fold belt, the location of major block faults, and the trace of the base of the Honna Formation (detailed explanation in text).

AGES AND STYLES OF DEFORMATION

We recognize two episodes of compression-related folding and faulting. The first occurred before or during the initial stages of Middle Jurassic volcanism (Yakoun Formation; see also Lewis and Ross, 1989); the second took place sometime after the deposition of Upper Cretaceous conglomerate (Honna Formation). From the Middle Jurassic until the Late Cretaceous, the region was disrupted by steep dipping (extension?) faults (Fig. 2) that were active more than once.

Middle Jurassic folding

On the north shore of Cumshewa Inlet, about 1 km west of Dawson Cove, there is a profound angular unconformity between the Yakoun Formation (Middle Jurassic) and the Lower Jurassic Sandilands Formation of the Kunga Group. Beds of Sandilands siltstone dip 70° southwest, whereas breccias of the Yakoun Formation dip 30° northeast. The unconformity has more than a metre of local relief, formed by upward projection of individual siltstone beds. Internal deformation is restricted to the Sandilands Formation; isoclinal and chevron folds abound. Disharmonic folding across the unconformity is ruled out by field relations. This locality is crucial because it places close limits on the time of folding — late in Early Jurassic or early in Middle Jurassic time. The unconformity is exposed at other localities along both the northern and southern shores of Cumshewa Inlet, and on the south slope of Skidegate Inlet, between Transit Island and South Bay. At all localities the unconformity separates the Kunga Group (Upper Triassic through Lower Jurassic) from either the Longarm Formation (Lower Cretaceous), the Haida Formation (mid-Cretaceous) or the Honna Formation (Upper Cretaceous). On the south slope of Maude Island, Jakobs (1989) has shown that Yakoun volcanics overlie the Maude Group (Whiteaves Formation) unconformably, but poor exposure precludes a detailed assessment of angular relationships. We assume, for now, that Maude Group deposition was completed prior to folding; if correct, this further restricts the time of folding to Early Bajocian time.

Minor fold axes in the Kunga Group have a consistent west-northwest to east-southeast trend; axial plunge ranges from 0-90°. Bedding attitudes are consistently steeper than those in overlying Yakoun and younger strata, and Kunga beds are more intensely folded and faulted at the mesoscopic scale. The contrast is especially apparent along the north shore of Cumshewa Inlet, east of Dawson cove, and along the south slope of Skidegate Inlet, east of South Bay; at both localities, Yakoun and younger map units are gently folded, whereas the Kunga Group contains complex fold and fault structures.

Lewis and Ross (1989) give evidence for Triassic-Early Jurassic deformation based on an analysis of cleavage and grain rotation within the axial planes of folds; their analysis suggests that the Kunga Group was not deeply buried at the time of deformation. We surmise that little heat was involved, and that the cycle of deformation, uplift and erosion prior to Yakoun volcanism did not destroy the potential of the Kunga Group as a hydrocarbon source.

Late Cretaceous and/or early Tertiary folding

The entire stratigraphic succession was folded after deposition of the Honna Formation. Deformation was most intense to the west, along the Rennell Sound fold belt (Fig. 2). Here, beds belonging to the Yakoun Group and Longarm and Honna formations are steep-dipping to overturned. Slices of Yakoun volcanics are imbricated with the Karmutsen Formation and Kunga Group. The eastern limit of steep dips (i.e. eastern limit of the Rennell Sound fold belt) is abrupt; beyond it, are more open fold forms illustrated by Lewis and Ross (1988). Is there an explanation for the abrupt eastern limit to steep dipping beds in the Rennell Sound fold belt? We speculate that a pre-existing block fault helped localize deformation.

Higgs (1988, in press) interpreted the Honna Formation as a foreland basin deposit, derived from a thrust sheet supported by an ancestral Sandspit thrust fault. We see no structural evidence to support the notion that northern Moresby Island was part of a Late Cretaceous thrust and fold belt. If anything, deformation proceeded from southwest to northeast judging by the greater amount and complexity of shortening within the Rennell Sound fold belt.

Late Jurassic through Tertiary block faulting

In a general sense, the geology of northeastern Moresby Island can be described in terms of three northwest-trending stratigraphic belts: Yakoun on the east, Haida in the centre and Longarm with and without Yakoun on the west (Fig. 2). Each stratigraphic belt is separated from the other by a steep, pre-Honna Formation fault; yet each belt overlies, unconformably, the same substrate: Kunga Group strata. The middle block has no Middle Jurassic Yakoun or Lower Cretaceous Longarm stratigraphy, the western block is missing the mid-Cretaceous Haida Formation, and the eastern block has a thick Middle Jurassic Yakoun succession but no Lower Cretaceous Longarm strata and very little of the mid-Cretaceous Haida succession. The Honna Formation overlaps all three blocks. We have yet to make a detailed analysis, but it is hard to escape two conclusions: 1) the faults separating each block were active more than once; and 2) these faults control the distribution of stratigraphy. We are now trying to determine if and how these structures influenced the distribution and composition of sedimentary facies and thicknesses during sedimentation. For example, Fogarassy and Barnes (1989) noted that basal Haida sandstones are more mature and contain greater primary porosity adjacent to the eastern margin of the Rennell Sound fold belt; this also coincides with the boundary between western and central blocks (Fig. 2).

The boundary between western and central blocks can be traced from eastern Louise Island toward Long Inlet. In their discussion of stratigraphic relations around Long Inlet, Haggart et al. (1989) noted the lack of Haida Formation strata overlying the Longarm Formation; continuation of the block fault beneath Long Inlet would help explain the distribution of Haida strata on the east and Longarm strata on the west.

The eastern boundary of the Rennell Sound fold belt coincides with the projected trace of the block fault described above (Fig. 2). We suggest the block-fault boundary not only influenced the distribution of Upper Jurassic and Cretaceous strata, but served to localize strain during Late Cretaceous and or early Tertiary compression.

Block faulting did not end in the Late Cretaceous. The Honna Formation is cut by steep, northwest-trending faults south of Kwuna Point and near the head of Saachs Creek; Maude Island is also cut by a post-Haida fault having the same orientation. Each fault displaces the eastern side down, and each parallels the Sandspit Fault.

QUESTIONS ABOUT LATE TERTIARY CRUSTAL FLEXURE

Evolution of the Queen Charlotte Basin has been interpreted in terms of simple crustal flexure (Yorath and Hyndman, 1983). In their model, upward deflection of the plate margin (i.e. western Queen Charlotte Islands) caused downward deflection of the plate interior (i.e. Hecate Strait). But simple flexure does not account for the remarkably uniform elevation of exposed Karmutsen and Kunga rocks within the Rennell Sound fold belt as it crosses northern Moresby Island (Fig. 2); it fails to explain why the pre-Yakoun unconformity, exposed near present-day sea level along Cumshewa Inlet, does not dip toward the east; and stratigraphic units on land do not have a preferred eastward dip. We know that block faulting was active during Late Jurassic, Early Cretaceous, Late Cretaceous and probably Paleogene times. Is it possible that faults like the Sandspit, responsible for subsidence of Hecate Strait, are Neogene manifestations of block faulting that has occurred, intermittently, since the Late Jurassic?

CONCLUSIONS

The Rennell Sound fold belt can be mapped, without interruption, from Skidegate Channel on western Moresby Island to the eastern side of Louise Island. The western side of the belt contains imbricated slices of Karmutsen volcanics and Kunga limestones; the eastern side consists of steep-dipping Cretaceous strata, mainly Honna conglomerate or Haida sandstone and shale. Presumably, this structural belt extends offshore and may be visible on seismic reflection records.

East of the Rennell Sound fold belt, Middle Jurassic through Upper Cretaceous strata are gently folded and cut by steep dipping block faults. Kunga Group rocks, on the other hand, may be tightly folded and faulted everywhere. A profound angular unconformity separating folded Kunga Group (and Maude Group?) from younger strata demonstrates there were two periods of folding: one prior to Middle Jurassic Yakoun volcanism, and the other after deposition of the Upper Cretaceous Honna Formation.

Block faulting was intermittent, starting in the Late Jurassic and persisting into the Neogene; at least two faults control the distribution of Upper Jurassic and Cretaceous strata, suggesting they may also have influenced the thickness and distribution of sedimentary facies.

Significant Tertiary strike-slip faulting is not present on northern Moresby Island.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the excellent data base published by Sutherland Brown (1968); his maps, descriptions and interpretations are the foundation to our work. Assistance in the field was provided by Ken Hoffman, Charlie Greig and Mary Ann Annable — a hard-working, capable, high-spirited crew. Discussion with colleagues at GSC and at UBC is essential and appreciated.

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Evidence for Late Triassic-Early Jurassic deformation in the Queen Charlotte Islands, British Columbia[1]

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Abstract

Bedded limestones and calcareous siltstones of the Kunga Group (Late Triassic) at Sialun Bay on northwestern Graham Island are cut by numerous gently-dipping thrust faults with associated folds. These structures record a north-verging compressional event. Penetrative cleavages parallel to axial planes of folds formed by mechanism of pressure solution and grain rotation facilitated by loss of cohesion between grains. These mechanisms are consistent with deformation in poorly lithified rocks under elevated pore fluid pressures, placing the timing of deformation at slightly post-deposition, or Late Triassic-Early Jurassic.

Résumé

Des calcaires et des siltstones calcaires stratifiés du groupe de Kunga (Trias supérieur), se trouvant dans la baie Sialum dans la partie nord-ouest de l'île Graham sont traversés par de nombreuses failles chevauchantes à faible pendage, auxquelles sont associées des plis. Ces structures révèlent une compression se dirigeant vers le nord. Des clivages pénétrants, parallèles aux plans axiaux des plis, ont été formés par une dissolution par pression et une rotation des grains facilitée par une perte de cohésions entre les grains. Ces mécanismes sont compatibles avec la déformation de roches mal consolidées sous des pressions interstitielles élevées, et permettent de situer dans le temps cette déformation légèrement après la sédimentation ou au Trias supérieur-Jurassique inférieur.

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INTRODUCTION

Until recently, most deformation of Mesozoic strata in the Queen Charlotte Islands was thought to be the result of wrench faulting along major transcurrent fault systems (Sutherland Brown, 1968; Young, 1981). Regional models for the evolution of the Queen Charlotte Basin have been based on this assertion (Yorath and Chase, 1981). Regional and detailed geological mapping during the 1987 field season by Frontier Geoscience Program scientists revealed that much of the deformation present is attributable to several episodes of northeast-directed compression, and evidence for major wrench fault systems through the central Queen Charlotte Islands is lacking (Thompson, 1988; Lewis and Ross, 1988). It is believed that this deformation followed a period of continuous sedimentation spanning Late Triassic (Norian) through Middle Jurassic (Aalenian) time, and was likely synchronous with Middle Jurassic (Bajocian) volcanism.

A primary goal of the 1988 field season was to constrain the timing of compressional deformation to provide a framework on which to base models for basin evolution. To this end, both regional and detailed mapping was completed at various locations throughout the Queen Charlotte Islands. One area examined, on northern Graham Island (Fig. 1), has allowed the timing of the earliest compression to be determined, and is the subject of this paper. At this location, on the southern shore of Sialun Bay, Kunga Group rocks of Norian age are cut by thrust faults with associated drag folds. Detailed studies of structural fabrics preserved as axial planar cleavages in these drag folds show that the cleavages formed at low temperature-pressure conditions in unlithified or poorly lithified sediments. A 1:500 scale map has been completed of a 0.5 km2 area containing these features (Fig. 2) to document the style and geometry of mesoscopic structural features. Samples of the axial planar cleavage were collected for laboratory investigations of the processes leading to cleavage formation.

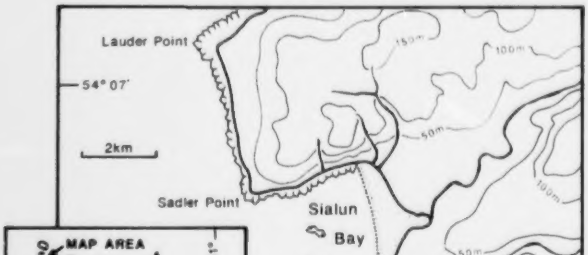

Figure 1. Regional map showing area of detailed mapping at southern Sialun Bay.

MAP DESCRIPTION

Lithologies exposed in the map area (Fig 2) comprise laminated to medium-bedded micritic limestones and calcareous siltstones of the unnamed black bedded limestone member of the Kunga Group. Subordinate fine grained, hornblende-plagioclase porphyry dykes are of limited areal extent and cut the thrust faults. The micritic limestones are rich in both disseminated and particulate organic material, which in southern Sialun Bay consists of mature to overmature kerogens (Vellutini, 1988). Abundant radiolaria are preserved as isolated calcite spherules. In silty lithologies, plagioclase crystals and volcanic fragments denote a large volcanic component. Layering within the sedimentary rocks is laterally continuous, and individual beds can be traced with little variation in thickness across much of the map area. The age of the sediments is constrained by the occurrence of the Late Norian bivalve *Monotis subcircularis*. This fauna is found in the southeasternmost exposures in the map area, and the remainder of the map area lies stratigraphically and structurally above the *Monotis* interval. Elsewhere in the Queen Charlotte Islands, the Kunga Group black bedded limestone ranges in age from Late Carnian to Late Norian (Carter et al., 1989).

Mesoscopic structures

Bedding throughout the map area dips gently or moderately southwest. A total structural thickness perpendicular to bedding of about 100 m is exposed; the total stratigraphic thickness represented is considerably less due to repetition of strata across faults and folds. The dominant structural features comprise faults that are subparallel to bedding and are continuous across the map area. These are marked by thin, recessive layers of fault gouge which are indistinguishable from fine clay layers where parallel to bedding, but are readily recognizable where they ramp across bedding. The faults dip gently southwest, and are regularly spaced 5-10 m apart. In one location, recognition of distinct bedding sequences within three consecutive fault bound packages documents a tripling of structural thickness across these faults. Duplex structures commonly occur where faults ramp across layering (Fig. 3). Tight to very tight folds are limited to strata immediately above and below fault surfaces. These folds commonly contain an axial planar cleavage which cuts across layering and is parallel to compositional layering outside the folded area.

Orientation data for faults, folds and cleavage are summarized in Figure 4. Fold axes lie within the overall fault plane orientation, and trend approximately east-west. The fold axes are roughly parallel to intersections between fault ramps and flats. This orientation, together with the spatial association of folds and fault surfaces, suggests the folds formed as fault drag features. The sense of asymmetry of

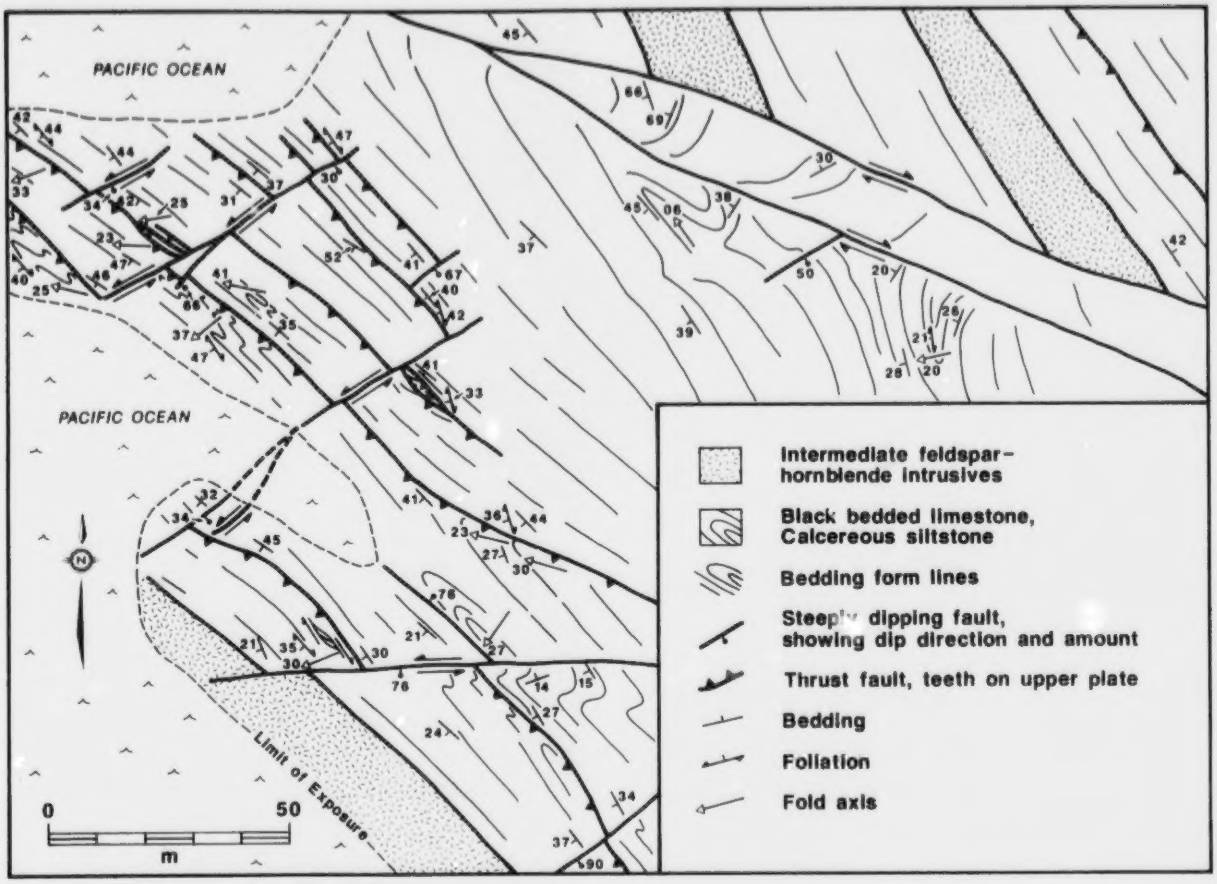
PACIFIC OCEAN
PACIFIC OCEAN
Limit of Exposure
N
0
50
m
Intermediate feldspar-hornblende intrusives
Black bedded limestone, Calcereous siltstone
Bedding form lines
Steeply dipping fault, showing dip direction and amount
Thrust fault, teeth on upper plate
Bedding
Foliation
Fold axis

Figure 2. Map of southern Sialun Bay. Structures are dominated by early gently to moderately dipping thrust faults, cut by later steeply dipping faults.

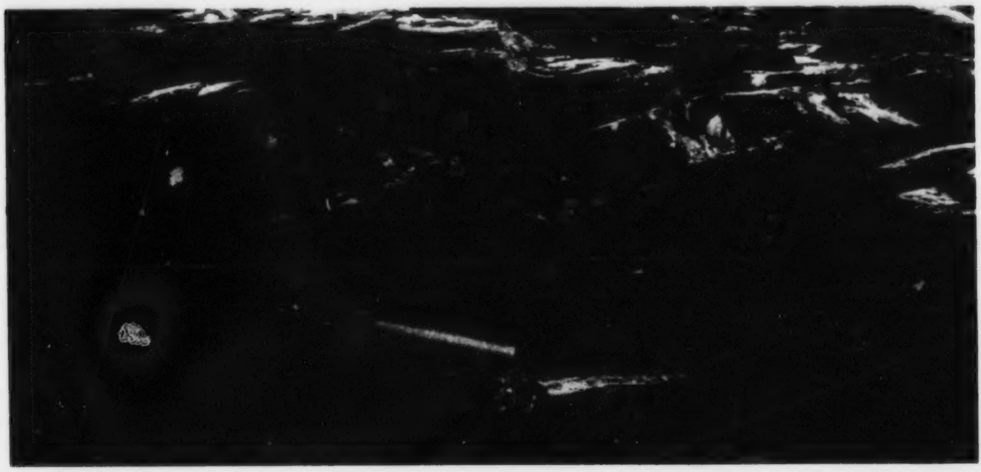

Figure 3. Duplex structures between adjacent bedding- parallel slip surfaces.

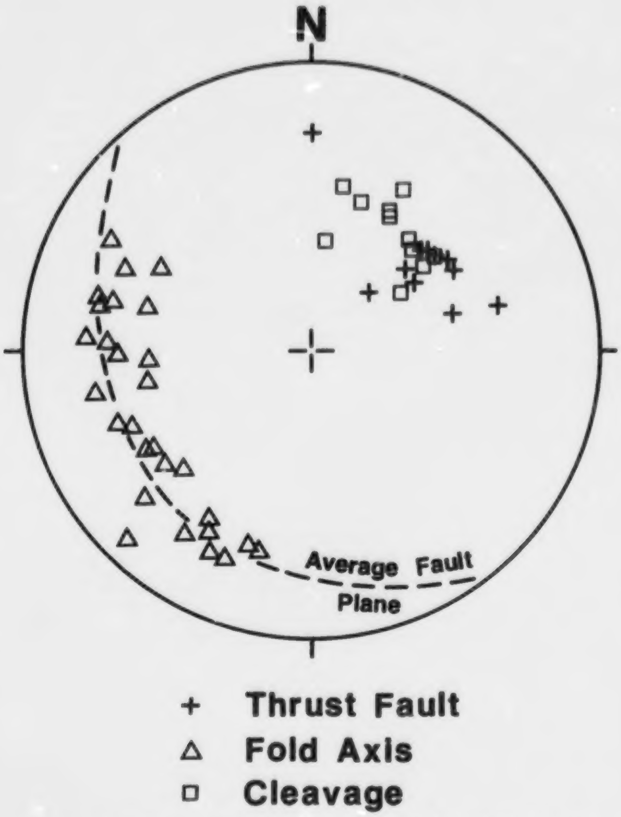

Figure 4. Stereographic projection of field data from map in Figure 2.

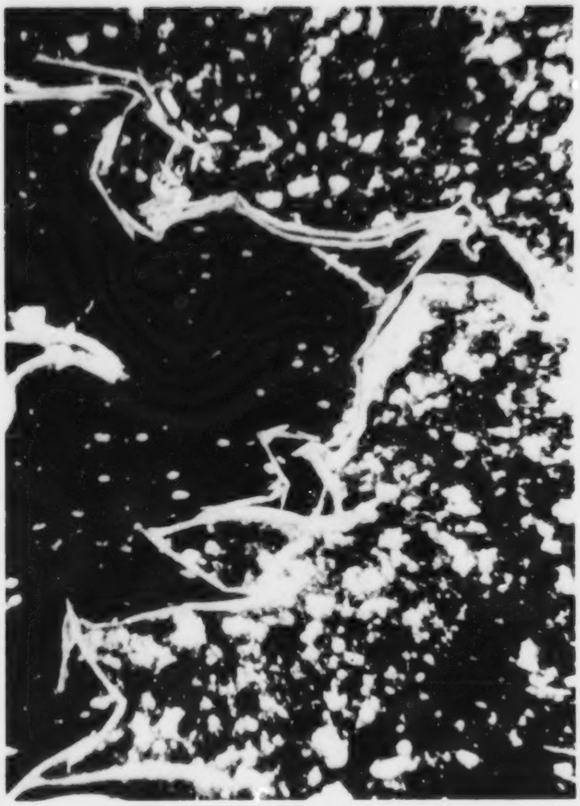

Figure 6. Photomicrograph of Monotis shell fragments aligned along cleavage plane. Cleavage in organic-rich micrite (right) is defined by alignment of platy mineral grains and calcified radiolaria spherules, silty plagioclase bearing lithology (left) lacks cleavage.

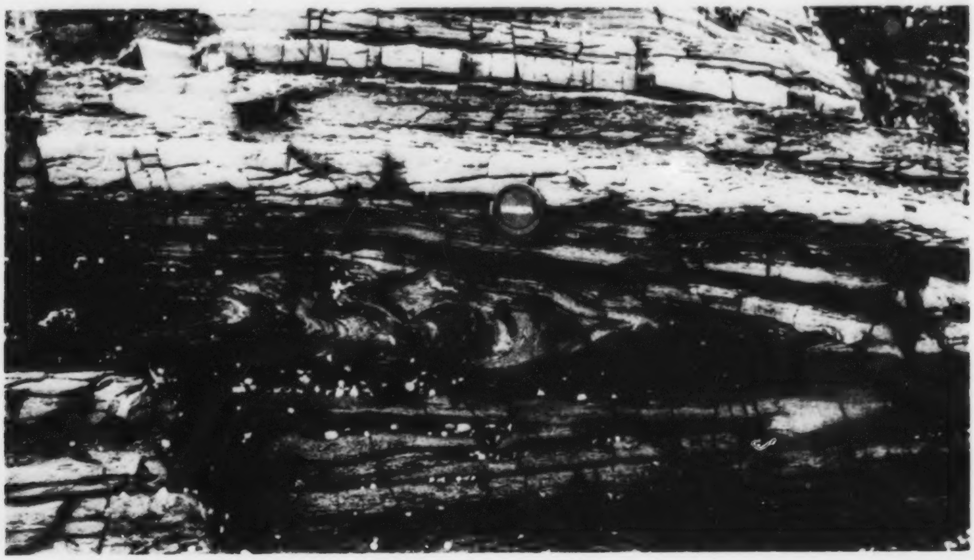

Figure 5. Asymmetric drag fold in strata immediately overlying fault surface.

folds and the geometry of duplexes and fault ramps document an overall north-directed transport direction along the major bedding parallel faults (Fig. 5).

The early faults subparallel to bedding are cut and offset by two sets of steeply dipping faults striking 055-065° and 115-125°. Movement on these surfaces has been determined from offset planar markers, drag folds, and slickensides. Faults striking 055-065° commonly display metres of sinistral offset, while those striking 115-125° have metres to tens of metres of dextral offset.

Microscopic structures

Samples of the axial planar cleavage were collected from several fold locations to evaluate the processes leading to cleavage formation. Optical examination of thin sections shows that the cleavages are defined by a preferred orientation of elongate grains, leading to a penetrative fissility. In micritic limestones, subrounded calcite grains representing calcified radiolaria outline elliptical shapes with long axes in the cleavage plane. Isolated particles of organic material commonly have highly elongate forms aligned in the cleavage plane. Plagioclase crystals in silty layers have only a weak preferred orientation, and show no evidence of grain breakage or internal strain. Despite this lack of intracrystalline deformation, thin silty layers may be completely disaggregated, and occur as isolated concentrations in the dominant micritic matrix.

In lithologies containing abundant *Monotis* valves, a strong cleavage is present along which shell fragments are aligned (Fig. 6). Although compositional layering may be at high angles to this cleavage, the shells have been folded or broken and rotated into the cleavage plane. A rough estimate of the amount of shortening across fold hinges within a given thin section may be obtained by unfolding individual shells (assuming simple rotation into the present configuration); values obtained by this method indicate up to 70% shortening. Large shells are often concentrated in layers bounding horizons of differing composition in the host rock. In one such example, a micritic layer with elongate calcite spherules is juxtaposed across a folded shell against a silty layer containing abundant plagioclase crystals. Although the silty layer experienced similar amounts of shortening as the cleaved micritic layer and the folded shell, no internal penetrative fabrics are present in the silty layer.

DISCUSSION

Mesoscopic structures exposed at southern Sialun Bay record a north-verging compressional event. The amount of shortening attributable to this deformation is uncertain; however, the abundance of thrust faults and other compressional structures, together with the observed repetitions of stratigraphy suggest it was considerable. Although isolated outcrops commonly lack evidence that clearly identifies structures to be the product of tectonic rather than sedimentary (slump) processes, the thickness of the deformed sedimentary layers, the lateral continuity of thrust faults and thrust sheets, and the absence of erosional scours, local unconformities, and drapes all suggest tectonic deformation. Kunga Group sedimentary rocks elsewhere on northern Graham Island lack the abundance of compressional features found at southern Sialun Bay, but detachment surfaces subparallel to bedding surfaces are ubiquitous in all occurrences of the Kunga bedded limestone member. We have also seen these types of detachments associated with isoclinal folding in Kunga Group bedded limestones to the south at Rennell Sound, and on Sandilands Island in Skidegate Inlet.

Microfabrics in deformed rocks constrain the timing of compressional deformation to be before the sediments were completely dewatered and lithified. The processes operative during deformation varied according to the lithology of the deforming layer. Silty layers deformed dominantly by grain boundary sliding and disaggregation of matrix between hard plagioclase grains, leading to the preservation of unstrained and unfractured grains. *Monotis* shell fragments were broken and reoriented into the plane of flattening, a process which could only occur if the surrounding matrix lacked cohesion. In micritic limestones, elongate calcite grains (calcified radiolaria) have likely attained their present geometry through pressure solution. This combination of disaggregation, grain boundary sliding, and pressure solution, and the lack of small scale fracture is compatible with low temperature deformation of sediments under unlithified conditions at elevated pore pressures (Knipe, 1986; Groshong, 1988). If the deformation had occurred in lithified sediments, brittle structures would have resulted in silty layers, and the rotation of large shell segments into the cleavage plane would have been prohibited by the cohesiveness of the enclosing sediments. Thus, the compressional event described here must have occurred shortly after deposition of Kunga sediments in Late Triassic or Early Jurassic time. The structures and microfabrics described were not seen in rocks of the overlying Sandilands Formation, suggesting that either deformation had ceased by the onset of Sandilands sedimentation, or that the differing lithologies present in rocks of the Sandilands Formation precluded development of such structures. Shales and siltstones of the Sandilands Formation may have provided a low-permeability cap, allowing pore pressures to build and inhibiting lithification in the underlying sediments. Bajocian age deformation associated with the intrusion of Yakoun Group feeder dykes is characterized by steeply dipping brittle shear zones and is distinct from the deformation described above.

The lack of any unconformities in post-Kunga Group rocks until the Upper Aalenian indicates that compressional deformation is not likely of regional extent, and is probably related to the closing and shallowing of the depositional basin. In this case, the structures observed may be the near-surface manifestations of east-west trending contractional faults in the underlying basement. These early contractional faults would have been reactivated during later deformation and could control the geometry of later structures and depositional sub-basins. Regional mapping has documented the importance of east-west trending faults in other areas (Lewis and Ross, in prep.).

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Preliminary structural studies of the Mesozoic rocks of central Graham Island, Queen Charlotte Islands, British Columbia[1]

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Abstract

Mesozoic rocks of central Graham Island are composed of a basal limestone unit conformably overlain by interbedded shales, silts and sandstones with ages ranging from Late Triassic (Norian) to Early Jurassic (Toarcian). Unconformably overlying these are Middle Jurassic (Bajocian) volcanic and volcanic derived sedimentary rocks. Major open to tight buckle-type folds in the area plunge gently northwest. Two major fault sets have been recognized. One set trends northwest and contains both normal faults and thrust faults. Field relationships suggest that the normal fault set is the younger. A second, minor, fault set trends northeast and may be related to strike-slip faulting.

Résumé

Les roches mésozoïques de la partie centrale de l'île Graham sont constituées d'un calcaire de base recouvert en discordance par des schistes argileux, des silts et des grès interstratifiés, dont l'âge varie du Trias supérieur (Norien) au Jurassique inférieur (Toarcien). Ces roches sont recouvertes en discordance par des roches volcaniques et des roches sédimentaires d'origine volcanique du Jurassique moyen (Bajocien). Des plis ouverts à serrés, formés par flambement dans cette région plongent légèrement vers le nord-ouest. On a reconnu deux réseaux importants de failles. Le premier, de direction nord-ouest, renferme des failles normales et des failles chevauchantes. Des relations établies sur le terrain indiquent que le réseau de failles normales est le plus jeune. Le second réseau, de moindre importance, a une direction nord-est et peut être associé à des décrochements horizontaux.

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INTRODUCTION

Sutherland Brown's (1968) geological map of the Queen Charlotte Islands indicated several areas of complex structural geology. Yorath and Chase (1981) presented a tectonic model of the Queen Charlotte Islands and the surrounding area based on Sutherland Brown's structural interpretations. Additional mapping includes that by Cameron and Tipper (1985), who published a geological map of the area north of Yakoun Lake, Graham Island, and by geologists currently involved in detailed studies (e.g. Thompson, 1988; Lewis and Ross, 1988).

Seven weeks were spent during the 1988 field season completing a geological map of an area in central Graham Island area (Fig. 1 and 2). This report includes a brief summary of preliminary results and a discussion of some conclusion drawn from the regional map patterns.

STRATIGRAPHY

Strata in the area comprise volcanic and sedimentary rocks of mainly late Triassic to Middle Jurassic age. Cretaceous strata outcrop in the northwestern limits of the area.

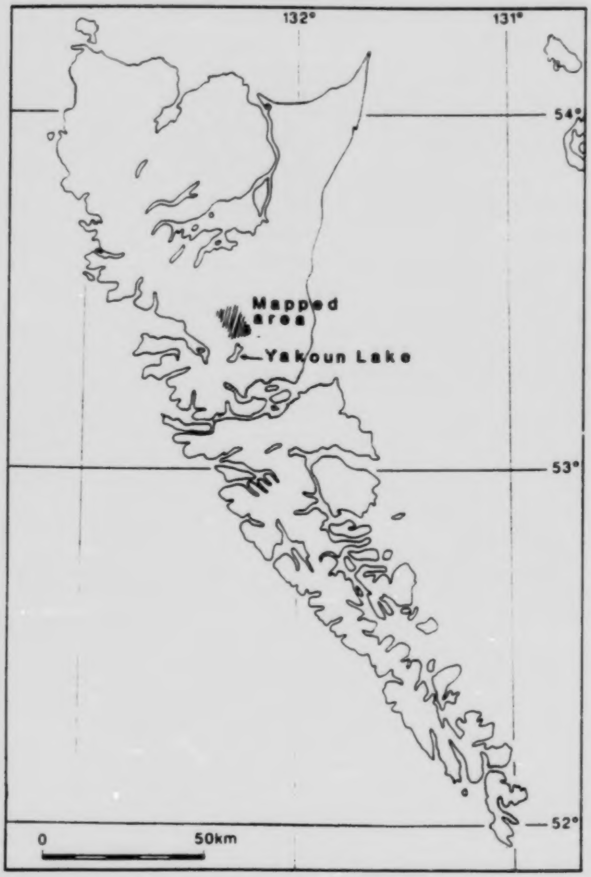

Figure 1. Location of area mapped on central Graham Island during the 1988 field season.

The oldest rocks recorded from the area belong to the black limestone member of the Kunga Group. This limestone is overlain by the Sandilands Formation of the Kunga Group which consists of thinly bedded fine sandstone, siltstone, shale and tuff.

Overlying the Sandilands Formation is the Maude Group, consisting of five formations (Cameron and Tipper, 1985). These are, in ascending order: 1) The Ghost Creek Formation, a dark grey shale and silty shale; 2) the Rennell Junction Formation, essentially composed of fine grained sandstone with interbedded siltstone, shale, and common limestone beds and concretions; 3) the Fannin Formation, consisting of mainly calcareous sandstone; 4) the Whiteaves Formation, a green-grey shale; and 5) the Phantom Creek Formation, a greenish fine to coarse grained sandstone. These formations range from Pliensbachian to Aalenian in age.

Unconformably overlying the Maude Group is the Middle Jurassic (Bajocian) Yakoun Group. The unit consists mainly of volcaniclastic sedimentary rocks but also contains some volcanic flows. The sediments range in grain size from shale to pebbly conglomerate.

Field identification of these different units is often difficult, but fossil collections have aided in identification.

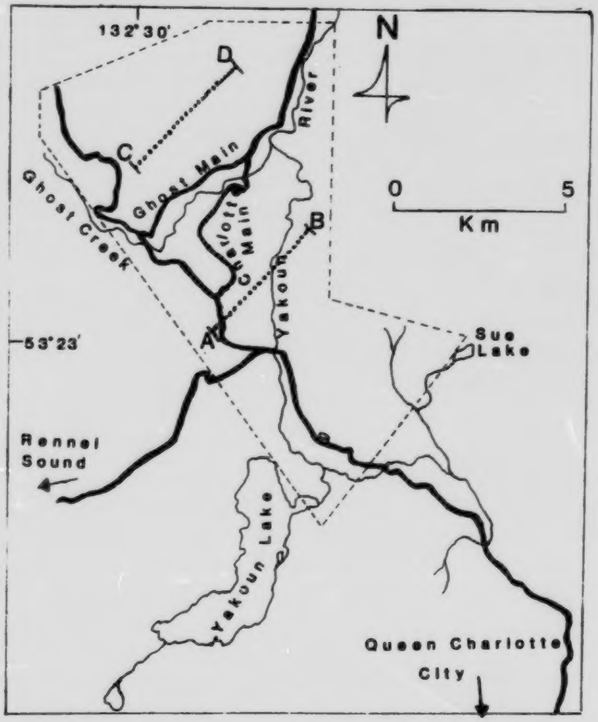

Figure 2. Location of cross-sections through the central Graham Island. Area mapped during the 1988 field season is marked by dashed lines. A-B and C-D are locations of cross-sections shown on Figure 3.

STRUCTURES

The major large-scale structures in the area are northwest trending faults. These faults are poorly exposed and minor faults exposed in roadcuts and quarries show little offset. However, the regional map patterns require several faults with large offsets. A second set of faults has a northeast trend and are not as continuous as the first set.

Two sets of megascopic folds are present in the map area. One set has fold axes plunging gently northwest. A second minor fold set, almost perpendicular to the first, trends northwest-southeast. Intensity of folding varies within different rock units. The Sandilands Formation commonly contains mesoscopic open to tight buckle folds. In contrast the overlying Maude and Yakoun groups are gently folded, and the folds have a larger wavelength than in the

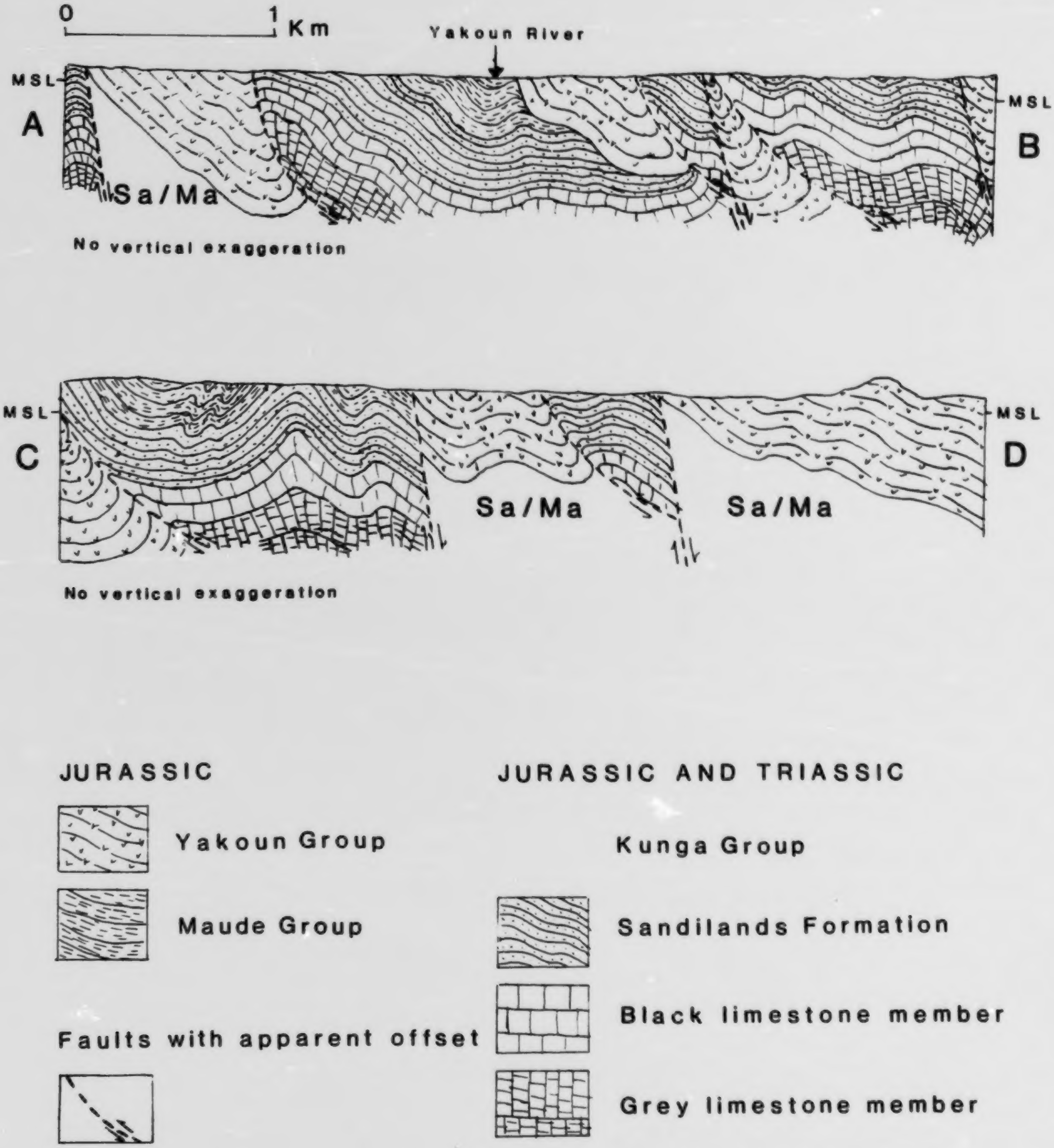
0
1 Km
Yakoun River
MSL
A
B
MSL
Sa/Ma
No vertical exaggeration
MSL
C
D
MSL
Sa/Ma
Sa/Ma
No vertical exaggeration
JURASSIC
Yakoun Group
Maude Group
Faults with apparent offset
JURASSIC AND TRIASSIC
Kunga Group
Sandilands Formation
Black limestone member
Grey limestone member

Figure 3. Structural section through southeastern part of the mapped area. Sa = Sandilands Formation; Ma = Maude Group.

Sandilands Formation. Such folds within the Yakoun Group are often recognizable only on map scale. Cleavage is generally poorly developed through all units from the Sandilands Formation up to the Yakoun Group.

The contact between the Yakoun Group and the underlying strata is rarely exposed. However, at one locality an unconformity between the Yakoun Group and the Sandilands Formation was seen, and at another outcrop an angular unconformity between the Yakoun Group and the underlying Phantom Creek Formation (upper part of the Maude Group) is exposed (shown diagramatically on Fig. 3). This unconformity appears to be folded.

DISCUSSION

The Triassic and Jurassic strata in the central Graham Island area have undergone several phases of deformation. Both normal and reverse fault offsets were seen on the outcrop scale, but most offsets have a displacement of less than a few metres.

One steeply dipping fault observed in outcrop juxtaposes the Yakoun Group and the Sandilands Formation in the southeastern area of the map.

Two structural sections with an approximate northeast trend were drawn through the area (Fig. 3 and 4). Mesoscopic structures suggest that both thrust reverse faulting and normal faulting have been active in the area, and the normal faults appear to be younger. Fold styles shown in the cross-sections supports the suggestion of thrusting in the area.

Structures mapped in the central Graham Island fit well with those observed by Thompson (1988) and Lewis and Ross (1988) further south in the area along Skidegate Inlet.

CONCLUSIONS

Much fieldwork remains before the structural history of the central Graham Island region can be outlined more definitively. Further mapping of the faults observed during the 1988 season will help to establish a model for the structural evolution and tectonic history of the area.

ACKNOWLEDGMENTS

The authors wish to thank R.I. Thompson and H.W. Tipper for invaluable aid during the summer 1988 field season. H.W. Tipper and P.L. Smith are thanked for help in identifying the fossil collection. Peter D. Lewis is thanked for excellent guidance through the stratigraphy of the area.

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Integrated ammonoid-conodont-radiolarian biostratigraphy, Late Triassic Kunga Group, Queen Charlotte Islands, British Columbia[1]

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Carter, E.S., Orchard, M.J., and Tozer, and E.T., Integrated ammonoid-conodont-radiolarian biostratigraphy, Late Triassic Kunga Group, Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 23-30, 1989.

Abstract

Ammonoids, conodonts, and radiolarians occur together in the Upper Carnian and Norian parts of the Kunga Group on Queen Charlotte Islands. The faunas provide a unique opportunity to establish a three-way integrated zonation for much of the Late Triassic. This complements what has previously been accomplished in northeast British Columbia using the ammonoid standard and associated conodonts of the Pardonnet Formation. The latter zonation, established in a mid-paleolatitude area, is applicable to the Kunga Group (Wrangell) sequences for the most part, but low paleolatitude aspects of some faunas is suggested. New conodont zonation for the Upper Carnian, and new radiolarian zonation for much of the studied interval is expected. New and existing fossil zonation will provide a fundamental key in sedimentological, stratigraphic and structural studies of the Upper Triassic both on the Queen Charlotte Islands and elsewhere.

Résumé

Des ammonoïdés, des conodontes et des radiolaires se retrouvent ensemble dans les parties du Carnien supérieur et du Norien du groupe de Kunga dans les îles de la Reine-Charlotte. Ces faunes offrent une occasion unique d'établir une zonation intégrée à trois niveaux pour une bonne partie de la fin du Trias. Cela complète les travaux déjà accomplis pour le nord de la Colombie-Britannique à l'aide de l'ammonoïdé type et des conodontes associés de la formation de Pardonet. La dernière zonation, établie dans une région de paléolatitude moyenne, est en majeure partie applicable aux séquences du groupe de Kunga (terrane de Wrangell), mais pour certaines faunes des aspects à des faibles paléolatitudes sont suggérés. Une nouvelle zonation basée sur les conodontes pour le Carnien supérieur et une nouvelle zonation basée sur les radiolaires pour une bonne partie de l'intervalle étudié sont attendues. Les zonations fossiles nouvelles et existantes constitueront une clé fondamentale pour les études sédimentologiques, stratigraphiques et structurales du Trias supérieur dans les îles de la Reine-Charlotte et ailleurs.

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INTRODUCTION

In the Queen Charlotte Islands, intensive biostratigraphic investigations of the Triassic part of the Kunga Group by the Geological Survey of Canada began in 1987 (Orchard, 1988a). Most of the principal Triassic outcrops delineated by Sutherland Brown (1968) (Fig. 1) have now been visited and sampled systematically by the authors and by other collaborators, particularly A. Desrochers (University of Ottawa) who is undertaking sedimentological studies (Desrochers, 1988). A further related project involves conodont geothermometry (Orchard, 1988b).

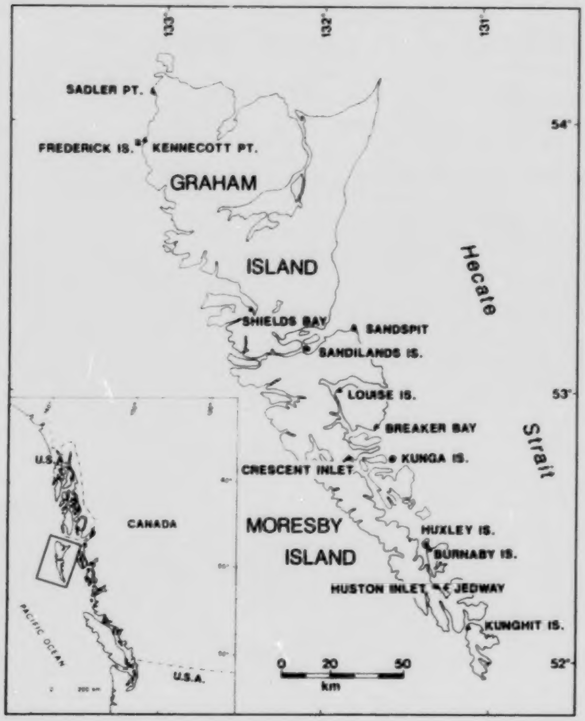
The purpose of the biostratigraphic study is to correlate in detail the Triassic strata in the Queen Charlotte Islands, using ammonoids, bivalves, conodonts and radiolarians. These results will provide a framework for sedimentary analysis and for environmental and tectonic interpretations of the Kunga Group. In addition, the common occurrence of the three principal fossil groups furnishes us with the potential to develop an integrated zonation (Fig. 2) for the interval that promises to have great application in Triassic studies in many different areas.

The original description of the Kunga Formation (Sutherland Brown, 1968) included the lower grey limestone member, the middle black limestone member and the upper black argillite member. In 1985, Cameron and Tipper elevated the Kunga Formation to group level and redefined the upper member as the Sandilands Formation. Macrofossil determinations have previously established that the grey limestone member is Upper Carnian and the black limestone member is Upper Carnian (Welleri Zone) to Upper Norian (Cordilleranus Zone). The age of the Sandilands Formation was in question for many years primarily because the basal beds (i.e. those lying above *Monotis* but below the first appearance of Sinemurian arietitid ammonites) were thought to be unfossiliferous (Sutherland Brown, 1968). Extensive ammonite and radiolarian collections from Kennecott Point made by H.W. Tipper and E.S. Carter in 1987 show that the Sandilands Formation is also Upper Norian.

BIOSTRATIGRAPHY

Grey Limestone

Evidence of fauna in the "grey limestone" or lower member of the Kunga Group is often most conspicuous as differentially weathered, silicified burrows and other bioturbation. Body fossils are much less common but include ammonoids, bivalves, echinoderms, and brachiopods; "algal" oncolites are locally common (Desrochers, 1988). Corals were reported by Sutherland Brown (1968), but none were noted during the present investigation. Microfauna includes acid-insoluble conodonts, ichthyoliths, and silicified holothurian sclerites. No radiolarians have been found in the grey limestone.


133°
132°
131°
54°
53°
52°
SADLER PT.
FREDERICK IS.
KENNECOTT PT.
GRAHAM
ISLAND
SHIELDS BAY
SANDSPIT
SANDILANDS IS.
LOUISE IS.
BREAKER BAY
KUNGA IS.
CRESCENT INLET
MORESBY
ISLAND
HUXLEY IS.
BURNABY IS.
HUSTON INLET
JEDWAY
KUNGHIT IS.
Hecate
Strait
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CANADA
PACIFIC OCEAN
U.S.A.
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km

Figure 1. Map of the Queen Charlotte Islands showing key localities cited in the text.

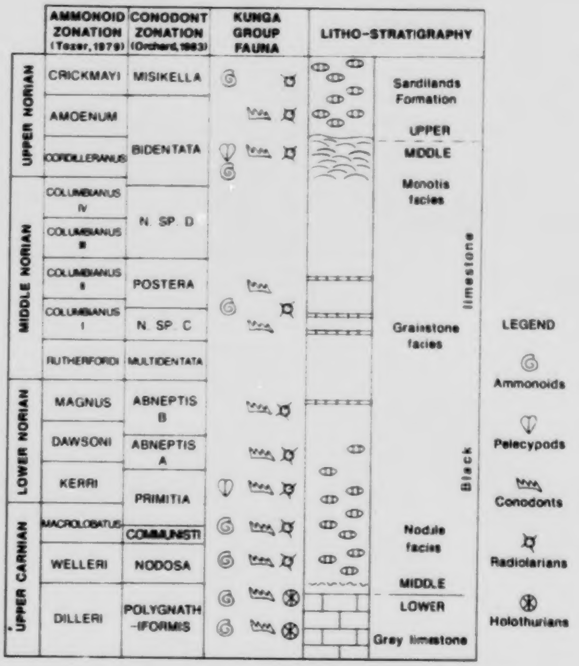

AMMONOID ZONATION (Tozer, 1979)
CONODONT ZONATION (Orchard, 1983)
KUNGA GROUP FAUNA
LITHO-STRATIGRAPHY
UPPER NORIAN
MIDDLE NORIAN
LOWER NORIAN
UPPER CARNIAN
CRICKMAYI
AMOENUM
CORDILLERANUS
COLUMBIANUS IV
COLUMBIANUS III
COLUMBIANUS II
COLUMBIANUS I
RUTHERFORDI
MAGNUS
DAWSONI
KERRI
MACROLOBATUS
WELLERI
DILLERI
MISIKELLA
BIDENTATA
N. SP. D
POSTERA
N. SP. C
MULTIDENTATA
ABNEPTIS B
ABNEPTIS A
PRIMITIA
COMMUNISTI
NODOSA
POLYGNATHIFORMIS
Sandilands Formation
UPPER
MIDDLE
Monotis facies
Grainstone facies
Nodule facies
MIDDLE
LOWER
Grey limestone
Black limestone
LEGEND
Ammonoids
Pelecypods
Conodonts
Radiolarians
Holothurians

Figure 2. Triassic fauna from the Kunga Group. Position of recovered fossil collections shown against the ammonoid and conodont zonation of the Upper Triassic.

Zone. The oldest collection, from within the grey limestone at Huston Inlet (Fig. 1, GSC loc. no. C-157006), includes *Sandlingites* sp. and new genera, whereas at the top of the grey limestone, or base of the black limestone, locally abundant arcestids occur on bedding surfaces, best displayed at Sadler Point. *Tropites dilleri* Smith occurs with arcestids in this stratigraphic position at Breaker Bay (GSC loc. no. C-157157).

Conodonts occur sporadically throughout the grey limestone. Two faunas are represented. One consists of a possible seximembrate apparatus of tiny elements, best developed at Huston Inlet. The Pa element of this assemblage is a segminate form that resembles the form genera *Cornudina* and *Misikella*, but its affinity is not yet resolved. The fauna has a restricted occurrence within the grey limestone, and it may represent a particular environmental niche. Rare elements of *Paragondolella* ex gr. *polygnathiformis* also occur with the segminate element assemblage, but most collections from the grey limestone consist entirely of this platform complex. This is true of collections made from the arcestid bed at the contact between the lower and middle members of the Kunga Group. This contact represents the drowning of the carbonate platform and is accompanied by faunal extinction. New fauna occurs above the junction of the two units.

Black Limestone

Coquinas of the thin shelled "pelagic" bivalves *Halobia* and *Monotis* characterize the middle member of the Kunga Group. In the lower part of the unit, dark carbonate mudstones locally contain large concretionary nodules that have yielded significant faunas of ammonoids, conodonts, and radiolarians (Fig. 2). This particular lithofacies extends through the Upper Carnian Welleri and Macrolobatus ammonoid zones, but above the Carnian-Norian boundary, the nodules, and their fossil fauna, become infrequent. The middle part of the black limestone is dominated by thin bedded grainstones (calcarenites) with less frequent lime mudstones and occasional intraformational conglomerates (Desrochers, 1988). Bivalve (mostly *Halobia*) coquinas occur throughout, but other macrofauna are rare. Conodonts indicate that much of the Lower and Middle Norian is represented in these beds. In the upper part of the black limestone, *Monotis* appears in great profusion and marks the onset of Upper Norian sedimentation.

Upper Carnian

Key sections for the Upper Carnian part of the black limestone occur on Kunghit, Burnaby, and Huxley islands, and at Sadler Point (Fig. 1). Also important are sections at Jedway Bay and Bluejay Cove. At each of these localities direct associations of ammonoids, conodonts and radiolarian occur and thereby provide a basis for an integrated zonation for the interval. The ammonoid standard (Tozer, 1967) has been employed in recognising several Welleri and Macrolobatus Zone levels based on species of *Anatropites*, *Discotropites*, *Hoplotropites*, *Thisbites*, *Tropiceltites*, and juvavitids amongst others.

Conodonts occur throughout the Upper Carnian sections and show gradual change beginning with the development of distinct though subdued anterior platform nodes in elements recovered a little above the base of the black limestone. One lineage of this 'paragondolellid-metapolygnathids' plexus underwent a progressive increase in platform ornamentation in terms of both posterior migration and sharpening of the nodes. Sharp-noded 'epigondolellids' first appear within the higher part of the Welleri Zone. These are herein regarded as a separate development from the Norian genus *Epigondolella* (in which they have generally been submerged, often as "*E. abneptis* (Huckriede)") and several new species as well as a new genus are recognized. A conservative 'paragondolellid' lineage, embracing elements with varying degrees of subdued anterior nodes, subsequently gave rise to both *Metapolygnathus communisti* Hayashi and *Epigondolella primitia* Mosher within the Upper Carnian Macrolobatus Zone. The conodont faunas allow recognition of several conodont zones within the Upper Carnian, shown in a preliminary way on Figure 2: both the *nodosa* and *primitia* zones can be subdivided. Isolated ammonoid-conodont occurrences in northeast British Columbia and Yukon Territory can be correlated with this zonation, and the general utility of the scheme shows promise.

Preliminary studies of the well preserved radiolarians indicate that an excellent radiolarian succession is present in Upper Carnian strata. The radiolarian fauna is extremely diverse, contains many short-ranging taxa, and promises excellent zonation for this interval. Upper Carnian faunas are characterized by abundant and highly diverse *Kahlerosphaera*, *Sarla* and *Capnuchosphaera*. In the lower part of the sequence *Bulbocyrtium reticulatum* Kozur and Mostler, *Capnuchosphaera theloides* De Wever, *Pentactinocarpus acanthicus* Dumitrica, *Praeheliostauras* aff. *levis* Kozur and Mostler, *Spongostylus tortilis* Kozur and Mostler, *S. carnicus* Kozur and Mostler, and Actinomid Group "A" (in De Wever et al., 1979) are common along with numerous species of *Haeckelicyrtium*, *Poulpus*, *Triassocampe*, *Xenorum*, *Xiphotheca and Praeheliostauras*. *Capnodoce* is rare. In the upper part of the sequence *Capnodoce* becomes more common and diverse. *Bulbocyrtium disertus (Blome)*, *Capnuchosphaera theloides* De Wever, *C. triassica* De Wever, *C.* aff. *lea* De Wever, *Capnodoce* aff. *anapetes* De Wever, *C. sarisa* De Wever, *C.* aff. *primaria* Pessagno and *Paleosaturnalis dotti* (Blome) have been observed; other paleosaturnalids are common.

Lower Norian

Lower Norian ammonoids are unknown in the Kunga Group, but some halobiids, notably *Perihalobia*, are thought to be of this age. Conodonts indicative of each of the three Lower Norian conodont zones recognized in northeast British Columbia (Orchard, 1983) are recorded on Queen Charlotte Islands. The (Upper) *primitia* Zone, which marks the base of the Norian and is recognized by the appearance of *Neogondolella navicula* Huckriede, occurs above rich Carnian faunas on Huxley Island and on southern Kunga Island, as well as elsewhere as isolated occurrences.

PLATE 1

Figure 1. *Bulbocyrtium* aff. *B. reticulatum* Kozur and Mostler. GSC 85936, x220. GSC Loc. No. C-157294, Burnaby Island (sample 87/BI-4C). Black Limestone, Welleri Zone.

Figure 2. *Cornudina*? sp. GSC 81241, x200. GSC Loc. No. C-157008, Huston Inlet (sample HU-5). Grey Limestone, Upper Carnian.

Figure 3. *'Metapolygnathus' nodosa* (Hayashi). GSC 81242, x80. GSC Loc. No. C-157380, Kunghit Is., west (sample KT-A25). Black Limestone, Upper Carnian.

Figure 4. *'Paragondolella' polygnathiformis* (Budurov & Stefanov). GSC 81243, x80. GSC Loc. No. C-150102, Burnaby Is., north (sample 87/BI-2). Grey Limestone, Upper Carnian.

Figure 5. *Spongostylus carnicus* Kozur and Mostler. GSC 85937, x175. GSC Loc. No. C-157294, Burnaby Is., north (sample 87/BI-4C). Black Limestone, Welleri Zone.

Figure 6. *"Epigondolella"* n. sp. G. GSC 81244, x80. GSC Loc. No. C-157037, Huston Inlet (sample SHU-2). Black Limestone, Upper Carnian.

Figure 7. *Metapolygnathus communisti* Hayashi. GSC 81245, x80. GSC Loc. No. C-157275, Kunga Is., south (sample 87/ASKU-10). Black Limestone, Upper Carnian.

Figure 8. *Podocapsa*? sp. 1. GSC 85927, x220. GSC Loc. No. C-140489, Kennecott Point (sample KPA-17). Sandilands Fm., Upper Norian.

Figure 9. *Xipha* sp. GSC 85939, x275. GSC Loc. No. C-140407, Sandilands Is. (sample EC-1). Black Limestone, Lower Norian.

Figure 10. *Capnodoce fragilis* Blome. GSC 85938, x175. GSC Loc. No. C-140407, Sandilands Is. (sample EC-1). Black limestone, Lower Norian.

Figure 11. *Neogondolella hallstattensis* (Mosher). GSC 81246, x120. GSC Loc. No. C-157110, Poole Inlet, east (sample EPO-1). Black Limestone, Lower Norian.

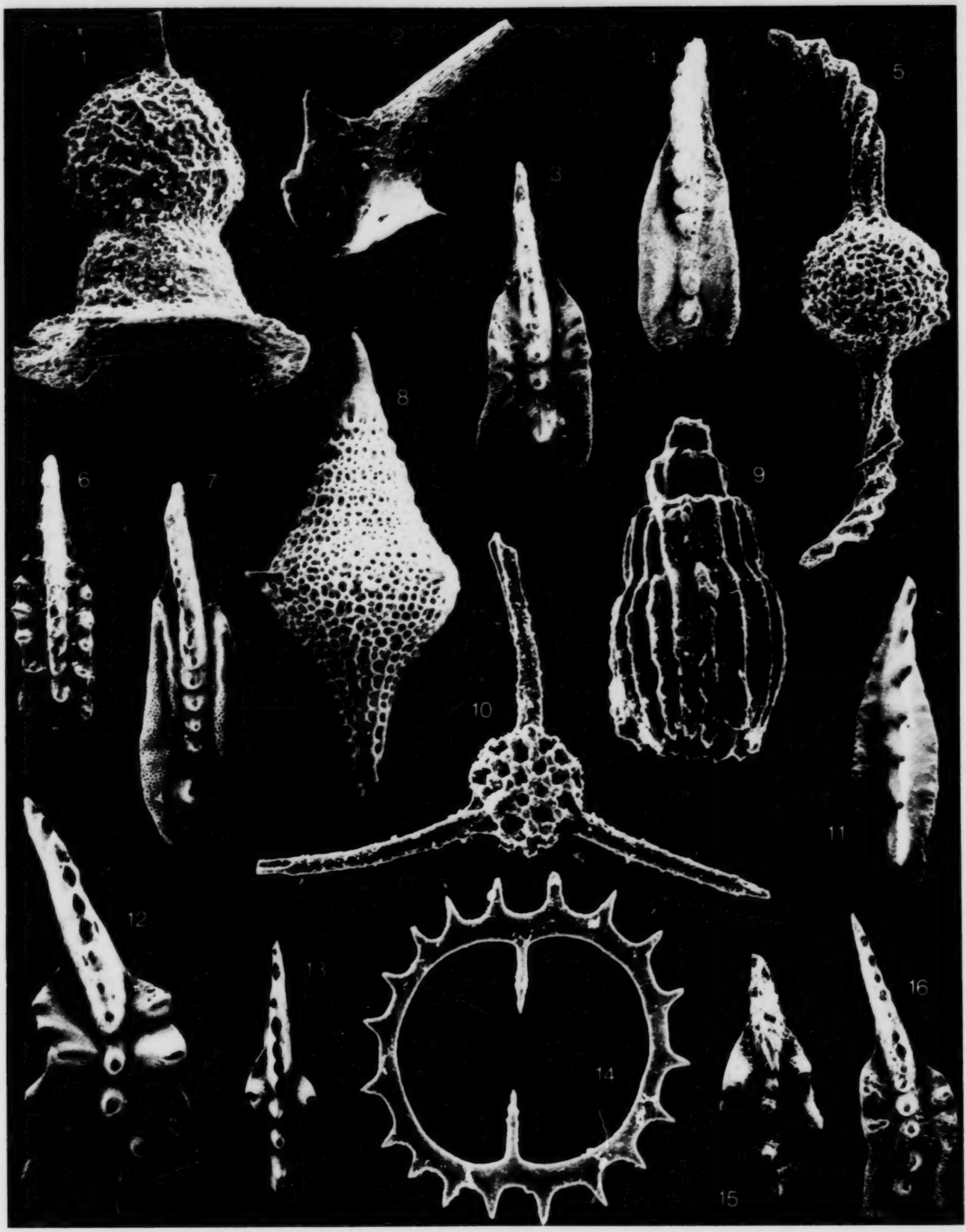
Figure 12. *Epigondolella triangularis* (Budurov). GSC 81247, x80. GSC Loc. No. C-157325, Burnaby Is., north (sample BI-13). Black Limestone, Lower Norian.

Figure 13. *Epigondolella bidentata* Mosher. GSC 81248, x100. GSC Loc. No. C-157344, Rose Inlet (sample RI-A6). Black Limestone, *Monotis* beds.

Figure 14. *Mesosaturnalis* sp. 1. GSC 85940, x220. GSC Loc. No. C-164674, Kunga Is., south (sample SKU-SP-1). Sandilands Fm., Upper Norian.

Figure 15. *Epigondolella postera* (Kozur & Mostler). GSC 81249, x90. GSC Loc. No. C-150131, Burnaby Is., north (sample 86/BI-25). Black Limestone, Middle Norian.

Figure 16. *Epigondolella primitia* Mosher. GSC 81250, x80. GSC Loc. No. C-157121, Huxley Is. (sample HUX-B9). Black Limestone, Carnian - Norian boundary.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16

Epigondolella abneptis subsp. A Orchard and *E. a.* subsp. B Orchard, indicative of the higher Lower Norian, are known from Burnaby Island, Poole Inlet opposite Howay Island, and elsewhere. Although *E. abneptis* subsp. B Orchard has been referred to *E. spatulata* (Hayashi) by some authors, a more appropriate name is *E. triangularis* (Budurov). The status of *E. abneptis* (Huckriede) itself is in doubt due to poor preservation of the holotype, and the mixed nature of the original collections from Austria. *E. spatulata* (Hayashi), here regarded as a 'Tethyan' or low latitude species, is known neither in the Kunga Group, nor in cratonal northeast British Columbia. On the other hand, a second Lower Norian Tethyan species, *Neogondolella hallstattensis* (Mosher), does occur on the south side of Poole Inlet and demonstrates a provincial faunal influence that is seen nowhere in cratonal western Canada sections.

Well preserved and diverse Lower Norian radiolarians are known chiefly from Frederick Island, Sandilands Island, Crescent Inlet and Burnaby Island where strata are well dated by associated conodonts. Future studies of these radiolarians should help refine and more closely date existing Triassic radiolarian zonation for western North America (Blome, 1984). Species of *Capnuchosphaera, Sarla, Kahlerosphaera* and *Capnodoce* dominate the assemblages. Commonly occurring species include *Capnodoce fragilis, C. malaca* and *Justium novum* described by Blome (1983, 1984) from east-central Oregon; *Capnuchosphaera theloides, C. triassica, Icrioma tectrancistrum, Syringocapsa batodes* and Actinomid Group "A" described by De Wever (in De Wever et al., 1979) from Greece, Sicily and Turkey; and *Capnodoce reusti, Capnuchosphaera deweveri and Kahlerosphaera norica* described by Kozur and Mostler (1979, 1981) from Austria and Hungary. Other genera making up the bulk of these assemblages include *Paleosaturnalis, Xenorum, Orbiculiforma, Paronaella, Triassocrucella* and many undescribed nassellarians.

Middle Norian

A single occurrence of the Middle Norian ammonoid *Himavatites* is known from the north side of Poole Inlet (GSC loc. no. C-157099), an occurrence referred to the Columbianus Zone. Many other occurrences of this zone are implied through comparison with Pardonet Formation ammonoid - conodont associations established in northeast British Columbia by two of us (Tozer, Orchard). Conodonts of the *Epigondolella* n. sp. C Orchard and *E. postera* (Kozur & Mostler) zones (Columbianus Zone equivalents) occur on Burnaby Island, north Poole Inlet opposite Howay Island, Huxley Island, and elsewhere. Notably absent are convincing representatives of the *E. multidentata* Mosher (Rutherfordi Zone equivalent) and *E.* n. sp. D Orchard (latest Columbianus Zone) faunas that occur in cratonal and epicratonal sequences in Western Canada. These conodont zones may be examples of North American, mid-latitudinal provincial faunas. Their absence from the Wrangellian sections of the Kunga Group may arise from the same biogeographical factors that resulted in the presence of the Lower Norian *N. hallstattensis* (Mosher).

Middle Norian radiolarians are rare and not well preserved in the Kunga Group; the few assemblages currently available are from Burnaby Island. Considering the high diversity of Radiolaria in the Upper Carnian, Lower and Upper Norian, their absence in the Middle Norian is almost certainly due to lack of preservation rather than reduced diversity. Limestone nodules are absent in this interval and the calcarenites have not yielded many faunas. Of those recovered, *Capnodoce* (especially *Capnodoce fragilis* Blome), *Cantalum, Paleosaturnalis* and *Pseudoheliodiscus* are the most common. *Paleosaturnalis artus* Kozur and Mostler and *P. tenuispinosus* Kozur and Mostler have been recognized along with forms similar to *Pseudoheliodiscus finchi* Pessagno (Pessagno et al., 1979). Rare specimens of *Mesosaturnalis* and *Livarella*? first appear in these assemblages as do a number of subpyramidally-shaped spumellarians with four arms and/or spines.

Upper Norian

Monotis is ubiquitous high in the middle part of the Kunga Group. The genus appears in great profusion in what is generally equated with the Cordilleranus ammonoid zone and, by definition, its equally sudden demise marks the base of the Sandilands Formation, or upper unit of the Kunga Group. Two species of *Monotis, M. salinaria* Bronn and *M. subcircularis* Gabb, are recorded, although they always occur in different beds. These species together constitute a biogeographically significant association indicative of low paleolatitude (Silberling, 1985, fauna B). Ammonoids are known in association with *Monotis* but they are generally flattened. Other fossils include the spherical hydrozoan *Heterastridium*, which occurs scattered amongst the monotids on some bedding surfaces: the best examples can be seen at Kennecott Point.

Conodonts from the *Monotis* beds are known from several localities and in all cases are referable to *Epigondolella bidentata* Mosher, which in some instances is associated with *Neogondolella steinbergensis* (Mosher) and ramiform elements. An outstanding problem with the *Epigondolella bidentata* populations concerns the need to delimit the variability within each Upper Norian faunule in order to refine the present long range attributed to the species.

Very few well preserved radiolarian assemblages have been collected from the *Monotis* beds during this study, although earlier Pessagno and Blome (1980) and Blome (1984) described species of *Betraccium, Cantalum, Ferresium, Laxtorum, Pantanellium,* and *Pseudoheliodiscus* from Kunga Island and established the *Betraccium deweveri* Subzone for the interval.

Sandilands Formation

This unit, formerly called the black argillite member of the Kunga Group, consists predominantly of dark siliceous siltstone and argillite. Ammonoids occur mainly in the upper part and are Hettangian and Sinemurian (Early Jurassic) in age. Late Triassic ammonoids indicating the Crickmayi

Zone are also known from Kennecott Point, namely *Choristoceras* cf. *C. rhaeticum* (Guembel). Other occurrences of post-*Monotis* Triassic ammonoids are rare and generally indeterminate; no Amoenum Zone indicators have yet been found.

Conodonts of the *Epigondolella bidentata* Mosher group are known from post-*Monotis* strata on Kunga Island and at Kennecott Point. Unpublished data from British Columbia and Nevada shows that *Epigondolella* ex gr. *bidentata* ranges through the Amoenum Zone and into the basal part of the Crickmayi Zone. Consequently only loose age constraints are provided by this taxon as presently conceived; differences between conodont faunas from the several Upper Norian levels are under review. No representatives of the latest Triassic *Misikella* have been recovered in spite of extensive sampling of the youngest Triassic strata.

Abundant, diverse and well preserved radiolarians from the lower part of the Sandilands Formation have been found at Kennecott Point, Louise Island, and Kunga Island. The potential for zoning the uppermost Triassic and identifying the Triassic/Jurassic boundary beds is excellent. Three preliminary radiolarian assemblages are recognized for Upper Norian strata lying above the *Monotis* beds (Carter, 1988; in press). Assemblage 1, the lower one, is tentatively correlated with the upper part of the Cordilleranus Zone, Assemblage 2 is thought to approximate the Amoenum Zone, and Assemblage 3 is correlated with the Crickmayi Zone. The uppermost Norian fauna, much of which is new, is dominated by species of *Betraccium, Pantanellium, Ferresium, Sarla, Canoptum, Podocapsa?, Theocorys?, Haeckelicyrtium, Squinabolella* and several new genera.

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APPENDIX

Locality register

Information is provided here for illustrated material.

GSC Loc. C-140407. Station SP-1, Sandilands Island, (86CAA(EC)-LST1); 53°10′16″, 132°07′19″. Kunga Group, black limestone member.

GSC Loc. C-140489. Kennecott Point, Section A, (87CNA-KP-A17); 53°54′48″, 133°09′18″. Kunga Group, Sandilands formation; 68 m above base of section, micrite nodule (100 × 15 cm), sample occurs 4.5 m below *Choristoceras* cf. *C. rhaeticum* Gumbel.

GSC Loc. C-157008. Huston Inlet, (87OF-HU-5); 52°15′54.1″, 131°18′12.7″. Kunga Group, grey limestone member; at 54 m.

GSC Loc. C-150102. Burnaby Island, N side, E of Section Cove, (87OF-BI-2); 52°25′, 131°18′. Kunga Group, grey limestone member; 10 m massive recrystallized grey micrite heavily veined with calcite, scattered recrystallized fossils - sparry outlines preserved, pentagonal crinoid columnals, brachiopods and snails, scattered siliceous nodules.

GSC Loc. C-150131. Burnaby Island, N side, E of Section Cove, (86OF-BI-25); 52°25′, 131°18′. Kunga Group, black limestone member; grey micrite interbedded with calcarenites.

GSC Loc. 157037. S Huston Inlet, SW of Pigeon Island, (87OF-SHU-2); 52°17′1.4″, 131°17′23.0″. Kunga Group, black limestone member; at 12 m, 0.5 m × 10 cm nodule.

GSC Loc. C-157110. E. Poole Inlet, (87OF-EPO-1); 52°22′0.5″, 131°17′36.3″. Kunga Group, black limestone member; micrite lense (10 cm) bracketed by squashed ammonoids and *Halobia*.

GSC Loc. C-157121. Huxley Island, (87OF-HUX-B9); 52°26′18.4″, 131°21′34.3″. Kunga Group; at 3 m, 10 × 70 cm nodule.

GSC Loc. C-157275. Kunga Island, S side, (87OF-SKU-A10); 52°45′18.3″, 131°33′58.7″. Kunga Group, black limestone member.

GSC Loc. C-157294. Burnaby Island, Section Cove, (87OF-BI-4C); 52°25′53.9″, 131°19′50.8″. Kunga Group, black limestone member; 22 m above exposed base of section. Dark lime mudstone concretion (100 cm × 30 cm). Welleri Zone ammonoids.

GSC Loc. C-157325. Burnaby Island, (87OF-BI-13); 52°25″58.9″, 131°19′42.6″. Kunga Group, black limestone member; nodule.

GSC Loc. C-157344. Rose Inlet, SE end, (87OF-RI-A6); 52°9′59.2″, 131°7′5.7″. Kunga Group, black limestone member; at 34 m above datum, *Monotis* beds.

GSC Loc. C-157380. W Kunghit Island, (87OF-KT-A25); 52°8′52.4″, 131°7′9.1″. Kunga Group, black limestone member; 10 cm lenticle at 218 m.

GSC Loc. C-164674. Kunga Island, S side, (87CNA-SKU-SP1); 52°45′37″, 131°33′37″. Kunga Group, Sandilands formation; isolated locality at head of small beach just E of Section D, micrite nodule (20 cm × 5 cm).

Lower Jurassic (Hettangian and Sinemurian) biostratigraphy, Queen Charlotte Islands, British Columbia[1]

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Tipper, H.W., Lower Jurassic (Hettangian and Sinemurian) biostratigraphy, Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 31-33, 1989.

Abstract

An exposure of Sandilands Formation at Kennecott Point, Queen Charlotte Islands of latest Triassic to mid-Early Sinemurian age spans the Triassic-Jurassic boundary. Early results suggest the presence of Lower, Middle, and Upper Hettangian ammonites. Other macrofossils, as well as microfossils, offer much new information on the Jurassic distribution of many faunal groups.

Résumé

Un affleurement de la formation de Sandilands, dans la pointe Kennecott, des îles de la Reine-Charlotte, dont l'âge varie du sommet du Trias au milieu du Sinémurien inférieur, couvre la limite entre le Trias et le Jurassique. Les premiers résultats indiquent qu'il existe des ammonites de l'Hettangien inférieur, moyen et supérieur. D'autres macrofossiles, ainsi que des microfossiles, offrent beaucoup de nouveaux renseignements sur la répartition jurassique d'un grand nombre de groupes fauniques.

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[1] Contribution to Frontier Geoscience Program

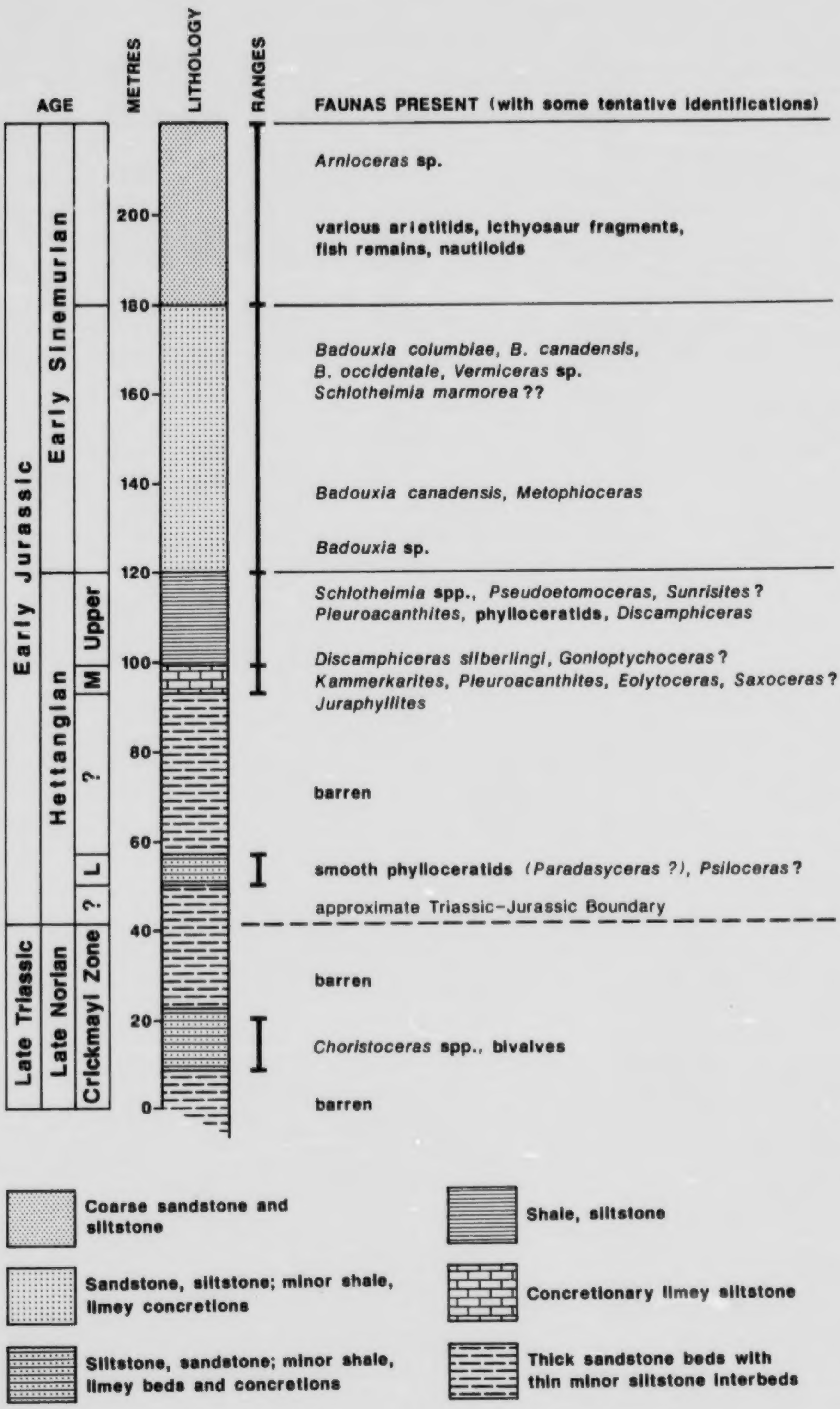
AGE
METRES
LITHOLOGY
RANGES
FAUNAS PRESENT (with some tentative identifications)
Late Triassic
Late Norian
Crickmayi Zone
?
Early Jurassic
Hettangian
L
?
M
Upper
Early Sinemurian
0
20
40
60
80
100
120
140
160
180
200
Arnioceras sp.
various arietitids, icthyosaur fragments,
fish remains, nautiloids
Badouxia columbiae, B. canadensis,
B. occidentale, Vermiceras sp.
Schlotheimia marmorea ??
Badouxia canadensis, Metophioceras
Badouxia sp.
Schlotheimia spp., Pseudoetomoceras, Sunrisites ?
Pleuroacanthites, phylloceratids, Discamphiceras
Discamphiceras silberlingi, Gonioptychoceras ?
Kammerkarites, Pleuroacanthites, Eolytoceras, Saxoceras ?
Juraphyllites
barren
smooth phylloceratids (Paradasyceras ?), Psiloceras ?
approximate Triassic–Jurassic Boundary
barren
Choristoceras spp., bivalves
barren
Coarse sandstone and siltstone
Shale, siltstone
Sandstone, siltstone; minor shale, limey concretions
Concretionary limey siltstone
Siltstone, sandstone; minor shale, limey beds and concretions
Thick sandstone beds with thin minor siltstone interbeds

Figure 1. Restored and simplified section of part of Sandilands Formation at Kennecott Point, northwestern Graham Island.

One and one-half months were spent in the field studying a section of Hettangian and lowest Sinemurian strata exposed at Kennecott Point on the northwest coast of Graham Island, Queen Charlotte Islands. The section is highly fossiliferous and possibly all Hettangian time and the earlier half of Early Sinemurian time are represented by macrofossils and microfossils. The exposure is an intertidal wave-cut bench with very little overburden.

The section is correlated with the Sandilands Formation of the Kunga Group (Cameron and Tipper, 1985) which was originally believed to be of Sinemurian age. The sequence of the formation at Kennecott Point begins with fairly limy beds in the Triassic (Upper Norian) above the Monotis-bearing beds (Cordilleranus zone) and generally coarsens upward to the top of the exposed section in the mid-Lower Sinemurian. So far as can be determined it is an uninterrupted sedimentary sequence.

The formation is composed of interbedded sandstone, siltstone, shale, concretionary limy siltstone, a few thin limy beds (5-10 cm thick), and thin beds of green to grey soft tuff. No conglomerate or grit-sized sand was noted. Generally the strata are thinly bedded (a few millimetres to five or six centimetres) but some beds of sandstone may be one or two metres thick. Ripple marks and crossbedding are present but are not common. Trace fossils are abundant. The section is intensely faulted but generally dips gently eastward.

The ammonite faunas present strongly suggest that there was a continuous depositional event across the Triassic-Jurassic boundary. The coarse sandstone at the boundary (Fig. 1) does not seem to be unique in the total section, but is only one of several sand intervals that punctuate an otherwise fine grained clastic sequence that is replete with a wide variety of fossils. The youngest ammonites in this section are about mid-Early Sinemurian in age, but elsewhere in the Queen Charlotte Islands, the formation is as young as Late Sinemurian, possibly in places latest Sinemurian. The genera identified here (Fig. 1) are preliminary determinations at best but those that are not queried are offered with some confidence. A comparison with Hettangian faunas of Nevada (Guex, 1980; D.G. Taylor, pers. comm., 1988) suggests that Lower, Middle, and Upper Hettangian strata are present at Kennecott Point. Many genera collected are not listed here as they have not been identified with any degree of confidence.

The Sinemurian beds have yielded an abundance of arietitids which although sparse at the 120 m level (Fig. 1), increase in numbers upward and are dominant in the upper 20 m; the first appearance of *Arnioceras* sp. is within 10 m of the top of the section. The *Badouxia* species are common and dominant in the lower beds of the Sinemurian. In most beds the ammonites are to some extent compressed so that specific identifications will be difficult.

In addition to ammonites, a wide variety of macrofossils were collected from this interesting section. Bone fragments of probably seven different icthyosaurs were found, six are Jurassic, one is Triassic. Most of the bones are ribs but some vertebrae and two skulls are among the material collected. Remains of several small fish were found, mainly in Sinemurian beds, and fish scales and separated bones are relatively common throughout the section. Two or three crustacea (crayfish?) were collected. A few leaves were found on bedding surfaces in the higher Sinemurian beds. Nautiloids, coleoids, bivalves, and brachiopods are common occurrences but never abundant. The diversity of faunas is unusual compared with the Sandilands Formation elsewhere in Queen Charlotte Islands.

E.S. Carter sampled many limy nodules and limy beds for the recovery of radiolarians and these were correlated with the ammonite faunas. The section was measured jointly and the whole study has been a collaborative exercise. Early returns from processing these samples suggest that radiolarians may be recovered in many samples, hopefully to give greater control in the barren zones (Fig. 1) and to prove the continuity of the depositional sequence.

If the section at Kennecott Point is as complete for latest Triassic to earliest Jurassic time as present information suggests, a very important source of information exists. It would be the first complete Hettangian section in Canada and the first section to span the Triassic-Jurassic boundary. If such is the case, much new information on various faunal groups should become available. Further fieldwork is planned.

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Toarcian (Lower Jurassic) biostratigraphy of the Queen Charlotte Islands, British Columbia[1]

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Jakobs, G.K., Toarcian (Lower Jurassic) biostratigraphy of the Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 35-37, 1989.

Abstract

The Toarcian stratigraphic succession in the Queen Charlotte Islands appears to be complete with a possible minor hiatus between the Whiteaves and Phantom Creek formations. The Lower Toarcian appears to be represented by Tiltoniceras propinquum, Dactylioceras kanense, *and* Taffertia. *The Middle Toarcian represents the bulk of the sequence and contains a fairly diverse fauna including* Phymatoceras, Haugia, *and* Peronoceras. *Upper Toarcian genera identified include* Hammatoceras, Sphaerocoeloceras, *and a form tentatively identified as* Esericeras. *The fauna is very diverse and promises to yield a detailed ammonite zonation which will be of great use to microfossil workers.*

Résumé

La succession stratigraphique du Toarcien dans les îles de la Reine-Charlotte, semble être complète, avec une lacune mineure possible entre la formation de Whiteaves et celle de Phantom Creek. Le Toarcien inférieur semble être représenté par Tiltoniceras propinquum, Dactylioceras kanense *et* Taffertia. *Le Toarcien moyen représente l'ensemble de la séquence et renferme une faune relativement diverse, dont* Phymatoceras, Haugia *et* Peronoceras. *Les genres du Toarcien supérieur identifiés comprennent* Hammatoceras, Sphaerocoeloceras *et une forme qu'on a essayé d'identifier à* Esericeras. *La faune est très variée et promet de fournir une zonation d'ammonites détaillée qui servira beaucoup aux micropaléontologistes.*

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INTRODUCTION

The Toarcian is the uppermost stage of the Lower Jurassic and is poorly understood in North America, primarily because of the lack of complete stratigraphic sections. The Toarcian in the Queen Charlotte Islands, however, contains a relatively complete stratigraphic sequence with a diverse and well preserved fauna. The primary goal of this study is a detailed ammonite zonation based on the Queen Charlotte Islands sequence because the sequence is potentially the type Toarcian for all of North America. This zonation would allow the correlation of the Queen Charlotte basin with Toarcian basins elsewhere and would also serve as a scale against which the radiolarian zonation could be compared (Carter et al., 1988).

The Toarcian in the Queen Charlotte Islands is represented by the Fannin, the Whiteaves and the Phantom Creek formations in the upper part of the Maude Group. These three formations are exposed primarily in central Graham Island along the Yakoun River and its tributaries, in the Skidegate Inlet area at Whiteaves Bay and on Maude Island. Several limited outcrops are also present in the Shields Bay and Rennell Sound areas, in the Marie Lake area, at Skedans Point on Louise Island, and possibly at Atli Inlet on Lyell Island (Fig. 1).

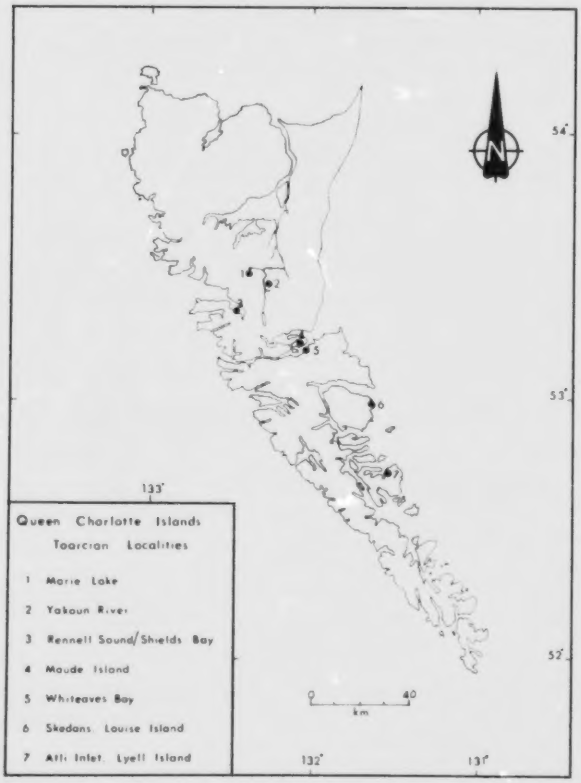

Figure 1. Toarcian localities on the Queen Charlotte Islands.

STRATIGRAPHY

The Fannin Formation is a heterogeneous unit ranging in age from Late Pliensbachian to Early Toarcian. Outcrops in central Graham Island are in fault contact with the overlying Whiteaves Formation, with the Lower Toarcian missing (Cameron and Tipper, 1985). The lowest Toarcian is present at Whiteaves Bay in Skidegate Inlet where it consists primarily of calcareous sandstone and tuffaceous shale with rare sandy limestone interbeds and lenses (Cameron and Tipper, 1985). The strata there are indurated and poorly fossiliferous but a number of taxa were collected, including *Dactylioceras*, *Taffertia* and *Tiltoniceras propinquum*, an association indicative of the Early Toarcian. The boundary between the Pliensbachian and Toarcian is difficult to determine because of the low fossil content. Below the *Dactylioceras* beds and above the last Pliensbachian ammonites, is an interval of about 25 m containing only *Tiltoniceras*, a genus that spans the boundary in North America (Smith et al., 1988). Further collections may succeed in delimiting the boundary with greater precision.

The Whiteaves Formation is a recessive, grey-green, silty shale with thin sandstone interbeds, tuffaceous layers and limestone concretions and interbeds. The formation outcrops on central Graham Island, Maude Island, Whiteaves Bay and at Skedans Point on Louise Island. It appears to be in fault contact with the underlying Fannin Formation and thus the uppermost part of the Lower Toarcian is probably absent in most places. The outcrop at Whiteaves Bay, however, contains a poorly exposed, unfossiliferous sequence lying above the Fannin Formation, and below a section of the Whiteaves Formation containing basal Middle Toarcian ammonites. This sequence is approximately 15 m thick and may represent the uppermost part of the Lower Toarcian, but the poor exposure and possibility of faulting make it difficult to determine. The outcrop is a beach exposure and changes from year to year, allowing the possibility that a more complete collection may be made in the future.

The Phantom Creek Formation is a greenish, glauconitic, fine to coarse grained sandstone with minor shaly interbeds and limestone concretions. These concretions are richly fossiliferous and can reach one metre in diameter. Its age spans the Late Toarcian and the Early Aalenian (Cameron and Tipper, 1985). The unit is present in central Graham Island and in the Shields Bay and Rennell Sound areas. An exposure on Maude Island (Section 4 of Cameron and Tipper, 1985), initially assigned to the Phantom Creek Formation, is separated from the Whiteaves Formation by a paleosol. The exposure is now tentatively thought to be Bajocian in age and part of the Yakoun Group based on lithology and an ammonite specimen (a sonninid). The thickest section (15 m) of Phantom Creek sediments is found along the Yakoun River (Section 11 of Cameron and Tipper, 1985) and the formation thins progressively to the south. The section at Road 59 in central Graham Island (Section 13 of Cameron and Tipper, 1985) has a thickness of only 6 m. On Maude Island, the Phantom Creek Formation is absent and the presence of the paleosol is evidence of a hiatus. The Creek 57 section in central Graham Island (Section 14 of Cameron and Tipper, 1985) has a very fossiliferous zone at the Whiteaves-Phantom Creek boundary and contains 'rotted' ammonites. The ammonite moulds in the sandstone contain casts composed of a brown, friable, clayey sediment similar to the paleosol on Maude Island. Ammonites in this zone include *Hammatoceras* and *Sphaerocoeloceras*, suggesting the presence of the European Levesquei Zone and the absence of the Thouarsense Zone (Fig. 3). This is further evidence for a hiatus between the Whiteaves and Phantom Creek formations. The main section on the Yakoun River (Section 11 of Cameron and Tipper, 1985) does not appear to have a hiatus, but the first 5 m above the contact are covered by trees and soil and may represent a fault trace. The preliminary and tentative assignment to *Esericeras* of the very large (up to 45 cm across) involute ammonites (H. Frebold, unpub. data; Cameron and Tipper, 1985) may be false, due to their association with *Hammatoceras* and *Sphaerocoeloceras*. In Europe, *Esericeras* is found below these two genera and it is probable that the large ammonites found in the Charlottes may be the macroconches (female dimorphs) of another genus, possibly *Hammatoceras*. A specimen collected from Creek 57 has the inner whorls of *Hammatoceras* and the involute, smooth outer whorls of the typical '*Esericeras*', supporting this idea.

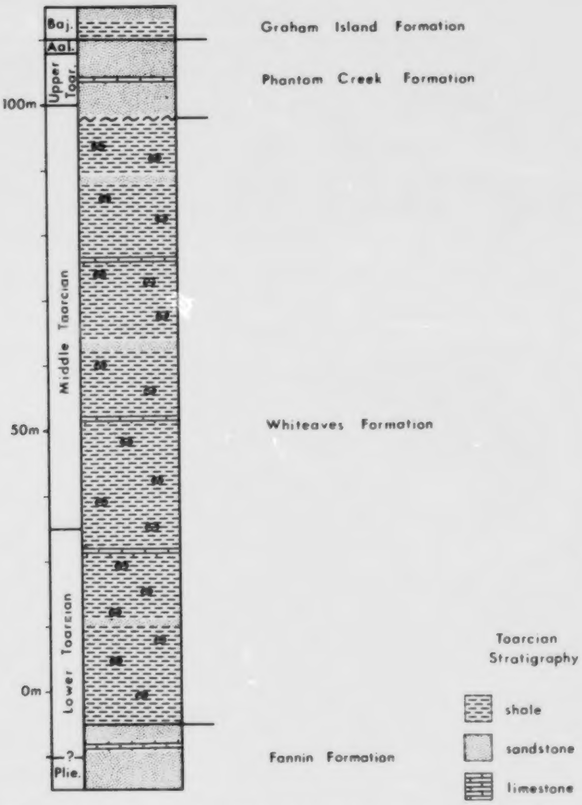

Figure 2. Generalized stratigraphic column for the Toarcian of the Queen Charlotte Islands.

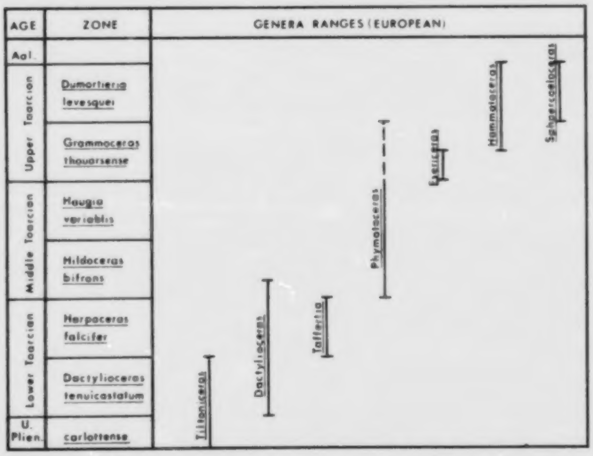

Figure 3. Some Toarcian genera identified from the Queen Charlotte Islands.

FIELDWORK TO DATE

The summer of 1987 was spent primarily measuring and collecting the Yakoun River sections, the section on Creek 57 and the section on Road 59. A collection was made from the Rennell Hill locality. During the summer of 1988, collections were made at Whiteaves Bay and at the Marie Lake Quarry. The Maude Island sections were examined but are poorly exposed and yield very few ammonites. New localities were found at Shields Bay, Marie Lake and Skedans Point on Louise Island. The Marie Lake Quarry exposes the upper part of the Whiteaves Formation and part of the Phantom Creek Formation. Isolated collections were made from the concretions of the Whiteaves Formation, however, the Phantom Creek Formation yielded little. At Shields Bay, shoreline exposures of metamorphosed Phantom Creek sediments were identified by the presence of dicoelitid belemnites which are typical of the Middle and Upper Toarcian. Some poorly preserved ammonites were collected at isolated outcrops. The Skedans Point outcrop was not visited by the author but examined by a mapping team. The section contains Fannin, Whiteaves and possibly Phantom Creek sediments. A possible Toarcian locality may be present at Atli Inlet on Lyell Island. Sutherland Brown (1968) collected some ammonites which could be Toarcian or Cretaceous, but he felt the beds belonged to the Maude Group. The ammonites resemble *Phymatoceras* and if they do indeed belong to this genus would indicate the presence of the Whiteaves Formation.

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Reconnaissance lithostratigraphy and biochronology of the Lower Cretaceous Longarm Formation, Queen Charlotte Islands, British Columbia

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Abstract

Strata of the Lower Cretaceous Longarm Formation outcrop over a wide region of the Queen Charlotte Islands. Lithofacies analysis and mollusc paleoecology of three study areas suggest that the Longarm represents an accumulation of principally shallow- water, shelf depth (< 200 m) deposits. The age of the formation in the contiguous outcrop belt in the central part of the archipelago is Hauterivian to possibly Aptian, as indicated by mollusks. In the northern part of the islands isolated exposures are of latest Jurassic to Hauterivian age.

Résumé

Des couches de la formation de Longarm du Crétacé inférieur affleurent dans une région étendue des îles de la Reine-Charlotte. L'analyse du lithofaciès et la paléoécologie des mollusques de trois régions d'étude suggèrent que la formation de Longarm constitue une accumulation de sédiments principalement mis en place en eau peu profonde (200 m) sur le plateau continental. Comme l'indiquent les mollusques, dans la zone affleurante contiguë de la partie centrale de l'archipel, la formation date de l'Hauterivien et peut-être de l'Aptien. Dans la partie septentrionale des îles, des affleurements isolés datent de la toute dernière partie du Jurassique à l'Hauterivien.

INTRODUCTION

The Longarm Formation was proposed by Sutherland Brown (1968) for the succession of Valanginian to Barremian strata which is exposed at many localities in the Queen Charlotte Islands. Long Inlet, formerly the Long Arm of Skidegate Inlet, was selected by Sutherland Brown as the type area for the formation, although a specific type section was not designated. He suggested that shallow marine, shoreline facies as well as deeper marine, trough deposits were represented in the formation. Subsequent workers have utilized the limited data presented by Sutherland Brown as a basis for expanded tectono-stratigraphic interpretations of the Early Cretaceous geological history of the Queen Charlotte Islands and adjacent areas (Yorath and Chase, 1981; Yorath and Hyndman, 1983).

Recent field studies have shown that some of the previous paleoenvironmental interpretations for the Longarm Formation should be reassessed. In view of the strong interest in the Cretaceous and Tertiary strata of the Hecate Strait region as possible petroleum reservoirs, a detailed Longarm stratigraphy is of prime importance.

In 1988, the author initiated a field program to study the stratigraphy and lateral extent of the Longarm Formation in the Queen Charlotte Islands. The focus is on the description of lithological units and a concurrent analysis of the molluscan paleontology. To date, molluscs, especially ammonites and inoceramid bivalves, have provided the most detailed and practical biochronological dating tool for the study of Mesozoic strata in the Queen Charlotte Islands. This report presents details of the lithostratigraphic succession of the Longarm Formation as well as preliminary interpretations of the molluscan biochronology.

LITHOSTRATIGRAPHY

Exposures of the Longarm Formation were studied at three principal locations in the Queen Charlotte Islands (Fig. 1). These included 1) exposures on the northwest coast of Graham Island; 2) the section at Long Inlet; and 3) extensive outcrops at Cumshewa Inlet.

In addition, other localities were visited where the Longarm Formation was thought to occur, or had recently been noted (i.e., Thompson, 1988).

White Point Exposures

Longarm Formation strata were mapped by Sutherland Brown (1968, Fig. 5) as outcropping on the northwestern coast of Graham Island, from 1.1 to 2.1 km south of White Point. These exposures will be referred to collectively as the White Point exposures (Fig. 2). Three distinct outcrop areas occur in this region. The first and largest is the most northerly of Sutherland Brown's mapped outcrops, the extensive tidal flat exposure located 1.1 km south of White Point; the second is the most southerly exposure mapped by Sutherland Brown, 1.9 to 2.1 km south of White Point; the last includes the offshore island just west of the northern, tidal flat exposure. This last outcrop is provisionally correlated with the Longarm Formation on the basis of its lithology.

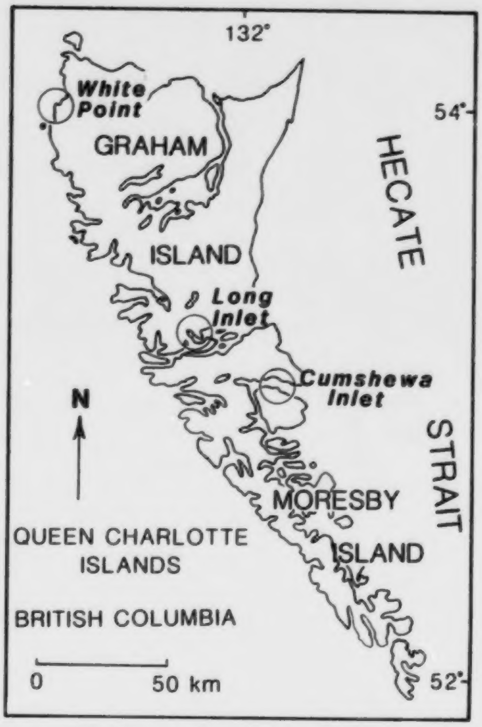

Figure 1. Principal study areas in the Queen Charlotte Islands.

The evidence presented below, however, indicates that these beds are older than any known Longarm strata in the region.

All these outcrops are exposed mainly in the intertidal region, and are commonly faulted. Two predominant fault patterns were noted, one trending 300° and the second, approximately perpendicular to the first, trending about 045°. Bedding is generally oriented with a southwesterly or west-southwesterly dip varying between 30° and 65°.

The base and top of the Longarm Formation were not seen in any section. No occurrences of mid-Cretaceous Haida Formation, or older Mesozoic Kunga Group rocks, which outcrop extensively to the north and south of the White Point region, were noted in association with the Longarm Formation exposures. Pyroclastics of the Tertiary Masset Formation overlie most of the area, and Longarm exposures were noted locally in fault contact with a distinctive and well indurated, undated volcanic breccia considered to be of probable pre-Masset age (C. Hickson, pers. comm., 1988). It is at present unknown if these volcanic rocks occur within the Longarm succession; they were not observed interfingering with Longarm beds in any of the sections studied at White Point and elsewhere in the islands.

Three major lithofacies were noted in the White Point exposures: conglomerate; sandstone with shell debris; and interbedded fine sandstone, shale and concretionary shale. Stratigraphic position suggests that the oldest strata in the region consist of a thick succession of cobble conglomerate. These beds occur extensively along the beach at the north-

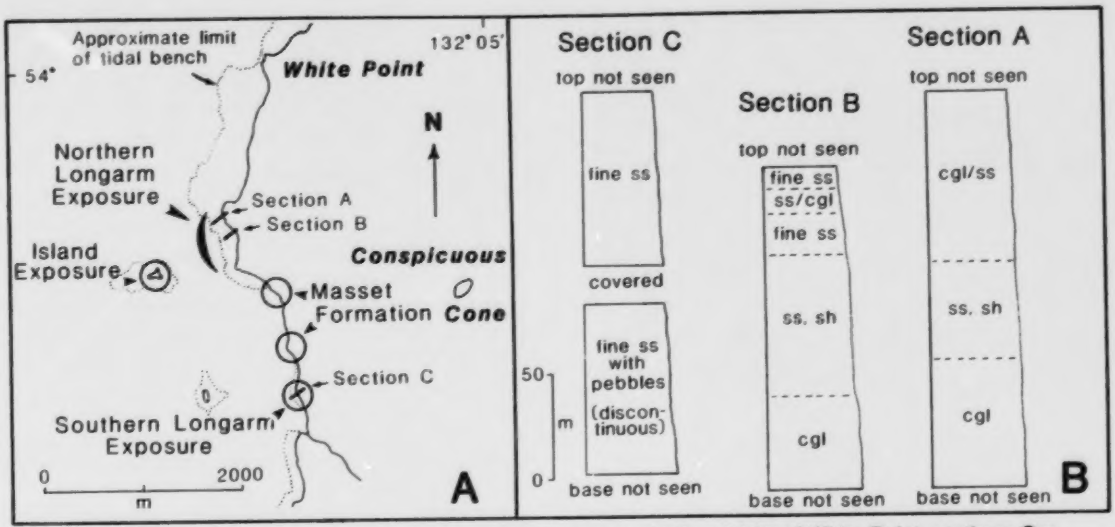

Figure 2. **A.** Sketch map of Longarm Formation exposures in the vicinity of White Point, northern Graham Island; **B.** Measured sections of Longarm Formation as exposed in the White Point area.

ern, tidal flat, exposure. The conglomerate weathers dark greenish grey to greenish brown and is very well indurated. The clasts are framework-supported, moderately well sorted, well rounded to subrounded cobbles, mostly ranging from 3 to 8 cm in diameter, with an observed maximum of 10 cm. The cobbles consist of approximately 90 per cent volcanics, 10 per cent granitic rocks, and minor argillite, chert, and calcareous shale. The matrix of the conglomerate consists of fine to coarse grained sand, rich in lithic grains. Occasional lenses of sandstone are noted within the conglomerate; these lenses are up to 25 cm thick and 5 to 10 m in lateral extent. Sixty metres of this conglomerate was noted in outcrop. Some of the lowest beds are locally in fault contact with the pre-Masset volcanic breccia noted above.

Conglomerate also occurs higher in the northern section. It is separated from the lower conglomerate just described by a 46 m (approximate) thickness of sandstone, shale, and concretionary shale. The thickness of the upper conglomerate unit is at least 82 m; its top extends beneath the sea. This conglomerate is compositionally similar to the lower one except that it includes common greyish buff concretionary shale clasts, generally very angular and occasionally of great size — some blocks reach 0.75 m in length. These blocks are presumably derived from the underlying unit of shale and sandstone. No fossils were noted in either of the conglomerate units.

The second major lithofacies observed in the White Point exposures consists of well indurated and compact, fine grained sandstone with shell beds, weathered greenish grey (Fig. 3A). This lithofacies occurs in all sections studied. Typically, these rocks are moderately well sorted, fine to medium grained lithic arenite, locally gritty. The sandstone is generally massive but shows some planar laminae; locally, accumulations of dark mineral grains define these laminae. A few thin, laterally discontinuous, platy shale horizons also occur. Petrified wood and, locally, coal seams were noted. At some sites, the sandstone has a highly petroliferous odour when it is broken. Laterally discontinuous lenses containing well rounded pebbles, a few cobbles, and broken shell debris occur at some levels, typically in the stratigraphically lower exposures of this facies (Fig. 3B).

Disarticulated molluscs and shell accumulations are common in this facies, and are locally very abundant. Some individual shells occur in life position in the sandstone but most are found in the thick, laterally extensive shell beds characteristic of the facies. The shell beds also contain well rounded pebbles. In some accumulations, shells are oriented randomly, in others individual valves are concave up (Fig. 3C). The most common taxonomic elements noted include *Buchia, Inoceramus, Arctica, Cucullaea, Columbitrigonia*, and belemnites. Locally, thick accumulations of *Inoceramus* prisms occur.

The third lithofacies noted in the White Point exposures consists of interbedded fine sandstone, shale, and concretionary shale. This facies tends to weather recessively except for the concretionary shale horizons, which are much more resistant. The shales are dark bluish grey to black, and the concretionary shale horizons are greyish buff. The sandstone of this lithofacies is compositionally similar to that occurring in the fine sandstone lithofacies described earlier, but lacks pebbles and shell debris. No molluscs were noted in these beds.

The southern White Point exposure is characterized principally by the second lithofacies described above; at the northern exposure, all three lithofacies occur in the section. Conglomerate characterizes the base of that succession and is overlain by interfingered accumulations of both of the other two facies as well as the upper conglomerate described previously. In Section A (Fig. 2) the upper conglomerate comprises more than 82 m of strata, but in the adjoining Section B the conglomerate is much thinner, occurring as a series of thin pebble beds within fine grained sandstone. Evidently the upper conglomerate horizon represents a channel deposit, which thins laterally into the adjacent sandstone.

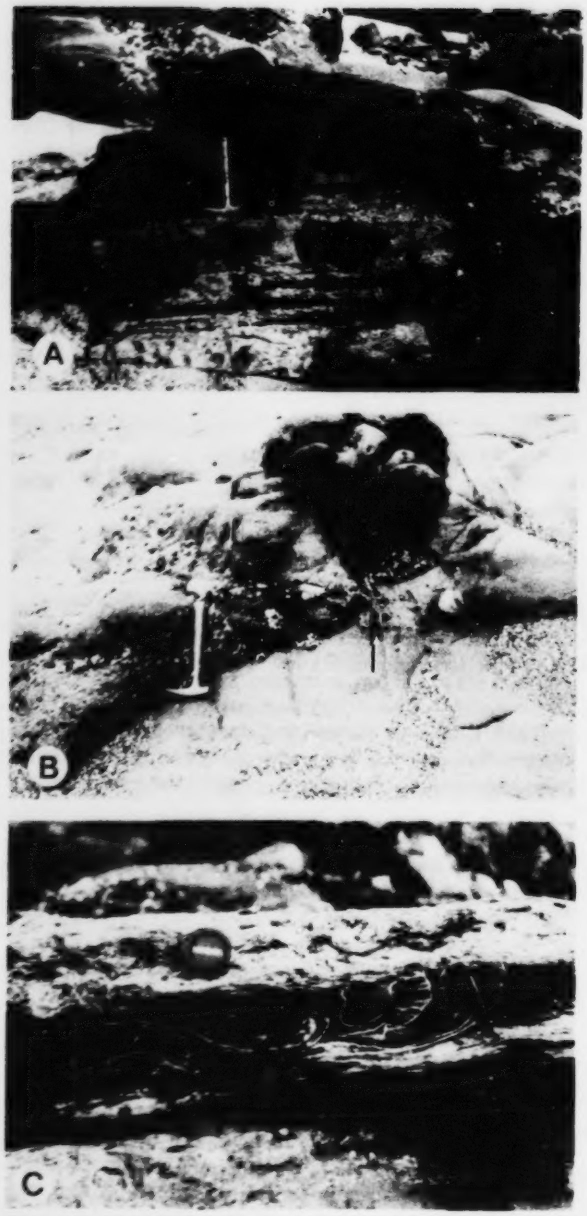

Figure 3. Fine grained sandstone lithofacies of the Longarm Formation in the White Point region. **A.** Massive to planar laminated sandstone exposed in the intertidal zone (GSC photo 204705-I); **B.** Closeup view of sandstone bed showing horizon of matrix- supported pebble/cobble conglomerate, indicated by arrows (GSC photo 204705-G); **C.** *Inoceramus* shell debris beds in fine grained sandstone; shells appear in cross- section as white outlines (GSC photo 204705-H).

The entire sequence is considered to reflect relatively shallow-water deposition. The horizons of abundant shell debris, typically robust valves occurring in laterally continuous accumulations, suggest deposition as lag deposits on the sea bottom. The presence of common belemnites, and *Buchia*, trigoniids, and other thick shelled bivalves also indicates a shallow-water interpretation for the succession. The presence of large sized angular clasts of intrabasinal composition in the upper conglomerate suggests that deposition occurred close to the source terrane.

Additional exposures of conglomerate and minor sandstone and shale occur on the offshore island west of the northern exposure. At the lowest tide, this outcrop is almost continuous with the tidal flat exposure. Rocks on this island were previously mapped as questionable Honna Formation on the basis of lithology. They are herein provisionally considered as possible Longarm Formation strata for several reasons. Firstly, they contain numerous horizons of shell hash — small fragments to whole shells of oysters, other bivalves, and brachiopods embedded in a fine to medium grained sandstone matrix. To date no described exposures of the Honna Formation conglomerate have contained any shell debris horizons. Secondly, they have a generally greenish colouration, in contrast to the Honna Formation conglomerate, which typically weathers to reds, browns, and black. Thirdly, these conglomerates are commonly dispersed through the sandstone rather than forming discrete, all-conglomerate beds as in the Honna Formation. Finally, the conglomerates contain belemnites which are not known from post-Longarm rocks in the Queen Charlotte Islands. Based on the fauna and sedimentary structures, these island conglomerates are also considered to be of shallow-water origin. The presence of common calcareous shale clasts within the conglomerate suggests a lithological similarity with the upper Graham Island conglomerate unit described above.

The age relationships of the various White Point exposures are not fully understood. Jeletzky (*in* Sutherland Brown, 1968) reported *Buchia crassicollis* (Keyserling), of late Valanginian age, from the most southern of the outcrops. Bivalves collected in 1988 from the northern outcrop have been tentatively assigned to *Inoceramus* cf. *paraketzovi* Efimova, suggestive of a Hauterivian age. Fossils collected earlier from the offshore island conglomerate include a poorly preserved buchiid fauna identified by Jeletzky (1984, p. 184) as late Late Jurassic in age. Thus, although the strata occurring on the offshore island are lithologically similar to the onshore exposures of the Longarm Formation, they appear to be significantly older. They may be equivalent to the unfossiliferous conglomerates in the lower part of the onshore sections. Alternatively, it is possible that they reflect a separate cycle of deposition, independent of the Longarm Formation sequence.

Long Inlet exposures

Longarm Formation strata are almost continuously exposed along the southwest shore of Long Inlet, at the northwestern end of Skidegate Inlet (Fig. 4). The strata occur as a steeply northeastward-dipping, locally overturned succession, which has been folded parallel to the regional trend of the Rennell Sound Fold Belt of Thompson (1988) (Lewis and Ross, 1988; Haggart et al., 1989).

The upper and lower limits of the formation in Long Inlet have not been seen. The contact with the younger Haida Formation is obscured beneath the waters of the inlet. In

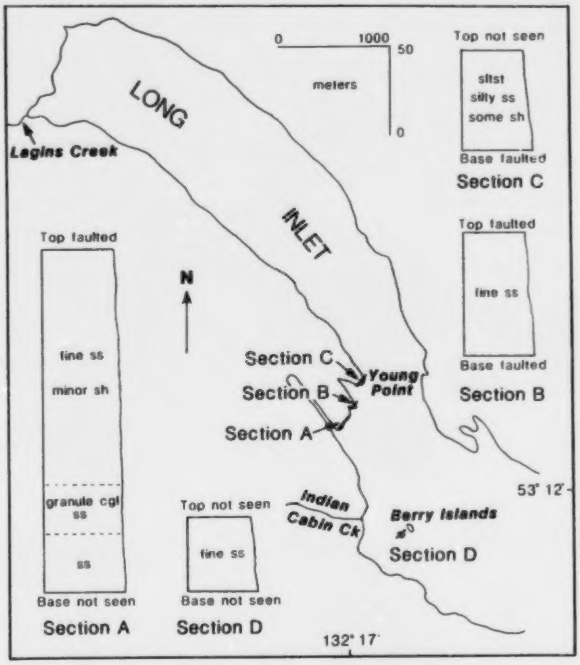

Figure 4. Sketch map of Longarm exposures in Long Inlet showing localities of measured sections.

Skidegate Channel, approximately 7 km southwest of Long Inlet, Longarm Formation strata outcrop in close proximity to Lower Jurassic Sandilands Formation and Middle Jurassic Yakoun Group strata (Lewis and Ross, 1988).

The distinctive cobble conglomerates characteristic of the lower part of the Longarm Formation sections in the White Point area are noticeably absent at Long Inlet. The extent of basal strata missing at Long Inlet is unknown, although the distinctive granule conglomerate described by Sutherland Brown (1986, p. 79; see below), which occurs in the lower part of the section in the inlet, is also known from near the base of the Longarm section at Cumshewa Inlet (see below), 30 km to the southeast.

The Longarm lithotypes present at Long Inlet are less varied than those seen near White Point. Good exposures are noted on the Berry Islands and also along most of the shoreline northwest from those islands, especially at Young Point (Section C) and the peninsula just to the south (Sections A, B). The strata preserved along the west shore of the inlet represent a single fining-upward sequence of sandstone, conglomeratic sandstone, siltstone, and shale.

The lowest rocks observed in this section outcrop at the base of Section A and consist of massive or planar laminated, possibly low-angle cross-stratified, medium grained, dark grey-green or greenish black sandstone. These rocks are strongly indurated and weather into platy fragments or blocks. No fossils were noted in these lowest beds.

Overlying these basal beds is a sequence (21 m thick) of interbedded sandstone and granule conglomerate (Fig. 5). These are the conglomerates described in detail by Sutherland Brown (1968). The maximum clast size observed in these conglomerates was 1.5 cm. The conglomerate occurs in relatively thin (5-90 cm) units, but one horizon 2.6 m in thickness was noted; typically, the conglomerate beds are much more extensive laterally. At Long Inlet these granule conglomerates were not noted in association with any other conglomerates or with distinctly larger clast sizes.

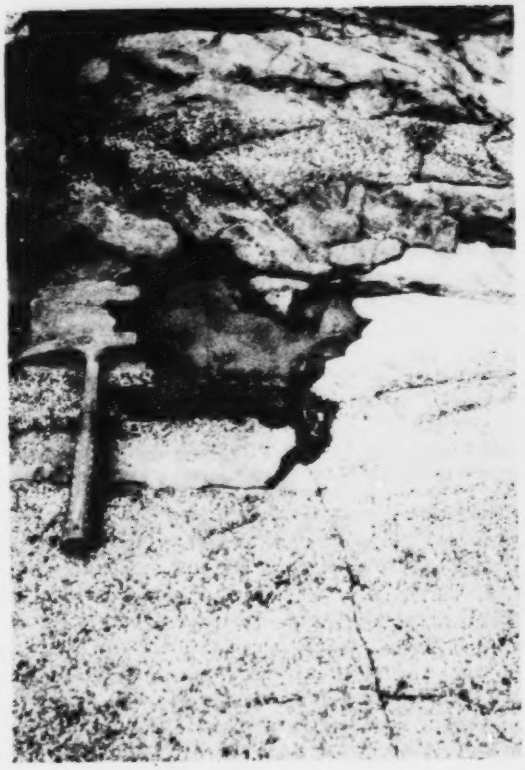

Figure 5. Interbedded granule conglomerate and sandstone beds of Longarm Formation, Long Inlet (GSC photo 204713-L).

The lowest fossiliferous horizons in Section A occur in strata overlying the granule conglomerates, a series of massive or planar laminated light green to greenish black, medium grained sandstones. This rock type also constitutes the exposures on the Berry Islands. The sandstones include some thin (<1 cm), laterally discontinuous black shales developed as depositional laminae, and several thin (5-10 cm), very dense, iron rich, fine grained sandstones. Fossil molluscs are preserved primarily as internal moulds, although fresh exposures may show some original shell. Fossils usually occur singly in the matrix, without any preferred orientation, but some shell lag accumulations several centimetres in thickness and two to three metres in lateral extent were noted.

Fossils, especially inoceramid valves, are abundant in the fine to medium grained silty sandstone and siltstone, which are the predominant lithotypes along the shore northwest of Young Point and on the point itself. These rocks also occur at the mouth of Indian Cabin Creek. Black shale sequences are much more common within these rocks as well, reaching 0.65 m in thickness. The inoceramid valves, some of which reach 0.3 m in length, are oriented parallel to bedding, with equal numbers of valves facing up or down. Also in these rocks, the fossils occur principally as internal moulds with some original shell being retained.

Sandy shale is the predominant lithotype in outcrops near the mouth of Lagins Creek. In sections where the shales are cleaner, calcite-cemented horizons occur, commonly forming laterally discontinuous concretionary zones (Fig. 6). Locally, the shale contains thin (< 10 cm) graded turbidite sandstone, which includes subangular and poorly sorted coarse grit and, locally, basal pebbles up to 2 cm in diameter. No fossils were noted in any of these shale exposures.

Although the Longarm Formation is extensively intruded by felsic to mafic igneous dykes and sills at Long Inlet, no evidence of interbedded volcanic rocks was seen.

The total thickness of Longarm Formation strata at Long Inlet is undeterminable. Nearly 200 m of overturned beds are exposed on the peninsula adjacent to Young Point and these strata are essentially repeated along strike for some distance to the northwest. This section is ultimately succeeded, however, by the shales that outcrop near Lagins Creek and which form much of the outcrop in the valley to the west (P. Lewis, pers. comm., 1988). An estimate of the additional thickness of these shales is 250 m.

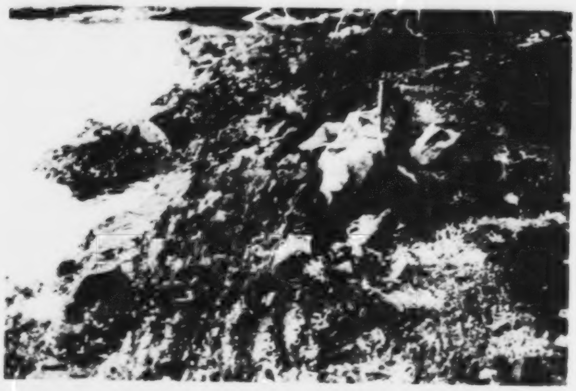

Figure 6. Calcareous shale concretion horizon in upper shale succession of Longarm Formation, Long Inlet (GSC photo 204705-N).

The Longarm Formation section at Long Inlet is a continuous, fining-upward succession considered to represent a single depositional sequence. Sutherland Brown (1968) reported *Simbirskites*? from Long Inlet, suggestive of a Hauterivian age. Although the precise locality for this specimen is not known, it probably came from either the Berry Islands exposures or the section southwest of Young Point. *Inoceramus* cf. *paraketzovi* Efimova was collected from the Berry Islands in 1988, giving support to a Hauterivian date for these localities. The occurrence of *Lytoceras* cf. *batesi* (Trask) in sandstone south of Young Point (upper Section A) suggests a Barremian age for this portion of the section. It is possible that younger horizons are represented in the overlying siltstone and shale. Thus, an age range of Hauterivian to Barremian or younger is indicated for the formation at Long Inlet.

Cumshewa Inlet Exposures

Longarm Formation strata are extensively exposed along the north shore of Cumshewa Inlet (Fig. 7), in general dipping gently to steeply northward. The formation unconformably overlies strata of the Lower Jurassic Sandilands Formation approximately 2.2 km east of the docks at Aero (Fig. 8A). The degree of angularity between the Longarm and Sandilands formations at this locality is slight, although elsewhere on the inlet it can be much greater (R. Thompson, pers. comm., 1988).

Lower strata of the Longarm Formation consist of well sorted, medium to coarse grained, planar laminated sandstone, locally pebble-rich and containing layers of pebble and cobble conglomerate. Good exposures of this facies can be found at the above- mentioned unconformity locality, as well as on the point 0.25 km farther east (Fig. 7, Section B). Conglomerate clasts are generally subrounded to subangular, ranging from 0.5 to 1.5 cm in diameter, but a few small cobbles 5 cm in diameter were noted. Conglomerate tends to occur as lenses within the sandstone, laterally quite extensive, but generally no more than 1 to 20 cm in thickness. Some are much smaller, and even isolated stringers of individual pebbles were noted locally. The conglomerate is predominantly matrix-supported and generally gradational with the surrounding sandstone matrix; however, grading of clasts within conglomerate lenses was noted at several sites. Single inoceramid valves are sometimes found within the conglomerate lenses.

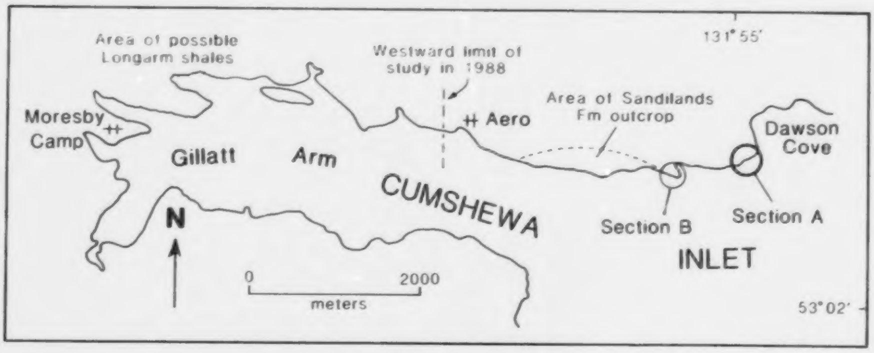

Figure 7. Sketch map of Longarm exposures in Cumshewa Inlet showing location of measured sections.

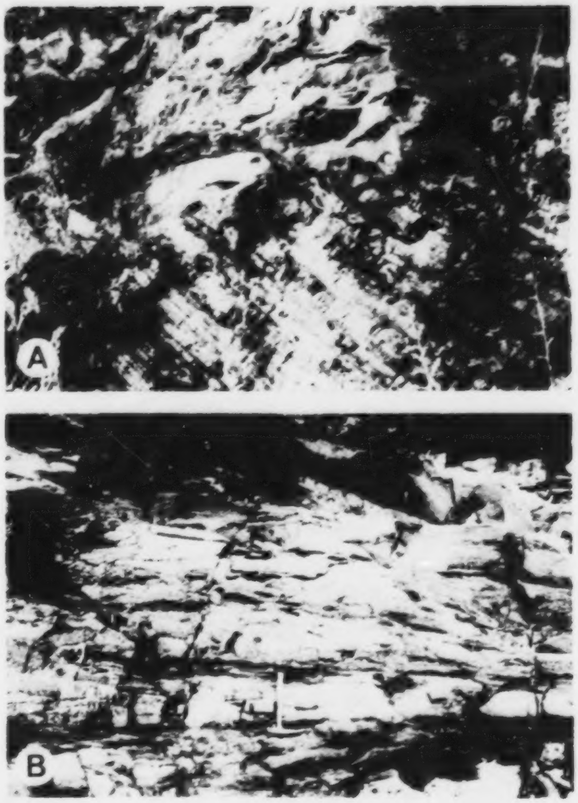

Figure 8. A. Unconformable contact (arrow) of basal, coarse grained sandstone and conglomerate lithofacies of Longarm Formation with underlying strata of the Lower Jurassic Sandilands Formation, Cumshewa Inlet (GSC photo 204705-O); **B.** Low-angle planar cross-stratification in medium to fine grained sandstone of the Longarm Formation, Cumshewa Inlet (GSC photo 204705-E).

Two horizons of spectacular accumulations of inoceramid valves are seen on the point described above. Valves in these accumulations are up to 25 cm in length, and commonly articulated. Single valves tend to be oriented subparallel to the bedding, with equal numbers facing up or down. The valves are commonly preserved as moulds where weathered, but include the prismatic layer where freshly exposed. Only the large, robust inoceramids and trigoniid bivalves were noted in the sandstone and conglomerate, usually in lag accumulations. These basal Longarm strata are thus considered to reflect shallow water deposition.

A float occurrence of granule conglomerate of the type seen at Long Inlet was noted on the beach just east of Aero, suggesting the presence of this distinctive unit in the hill above. This locality is considered to be very near the base of the formation.

Outcrops farther east (Fig. 7, Section A), appear to represent somewhat deeper water deposits. These strata are characterized by thick successions of massive or planar laminated to low-angle planar cross-stratified, fine to medium grained, feldspathic silty sandstone, greenish black to buff in colour (Fig. 8B). Some thin shale horizons occur within these strata. Conglomerate horizons are lacking in these beds, although shale pebbles are commonly seen. The rocks are extensively burrowed and fossil molluscs, mostly ammonites and bivalves, are very common. Ammonites are usually found singly, lying parallel to bedding. Plant debris and wood, even whole logs, were commonly noted in these strata and adjacent rocks are typically weathered orange to buff. A section of this facies, 116 m in thickness, was measured at this locality; faulting may duplicate or cut out some of the section.

Shale sequences were not noted in the Longarm Formation outcrops studied at Cumshewa Inlet in 1988, but R. Thompson (pers. comm., 1988) suggests that an accumulation of Longarm shales may be present just north of Moresby Camp in the western part of the inlet.

The fauna and sedimentary structures of the Longarm Formation exposures studied at Cumshewa Inlet indicate shallow-marine deposition. Fossil collections have only been studied cursorily but preliminary analysis suggests that *Inoceramus paraketzovi* Efimova, *I. colonicus* Anderson, *Quoiecchia aliciae* Crickmay, and *Columbitrigonia* sp. are present in the basal part of the succession. This assemblage suggests a Hauterivian to lower Barremian age (Jeletzky, 1970). Higher beds include *Shasticrioceras*, *Lytoceras* sp. cf. *batesi* (Trask) and *Lytoceras (Gabbioceras)*? sp., suggesting the presence of higher Barremian and possibly lower Aptian beds (see Anderson, 1938).

Other localities

Longarm Formation strata are exposed on the mountainside south of Alliford Bay, Skidegate Inlet. A thin section outcrops above shales of the upper Yakoun Group containing *Stephanoceras* (H. Tipper identification, 1988). Exposures are only seen in a quarry just below the level of the adjacent Honna Formation outcrops although Honna does not actually cap the hill above the quarry.

Strata exposed in the quarry include fine to medium grained greenish grey feldspathic sandstone with pebble and cobble lenses. The sandstone contains faint, low- angle planar cross-stratification and shell debris is occasionally concentrated along these stratification laminae. Conglomerate horizons are thin, generally between 5 to 12 cm in thickness, with well rounded clasts ranging from small pebbles to small cobbles (maximum 4 cm). Fossils are sometimes noted in the conglomerate horizons but most typically occur as shell lags on bedding or scour surfaces. Most fossils are leached moulds and some black carbonaceous material (possible periostracum?) was noted. Fossils collected at the quarry include common *Quoiecchia aliciae* Crickmay and *Columbitrigonia* cf. *jackassensis* Poulton, suggesting a Hauterivian to Barremian age. The abundance and diversity of the molluscan fauna and the presence of trigoniids suggest shallow water deposition.

DISCUSSION

Preliminary lithostratigraphic analysis of the Longarm Formation in three different regions of the Queen Charlotte Islands has shown that at these localities the formation represents a single depositional cycle. Strata studied at these localities consists of a basal sequence of coarse clastics, which fines upsection. Sedimentary structures and the included mollusc fauna indicate that these basal depositional sequences represent shallow water environments.

Shallow water depths were previously inferred by Sutherland Brown (1968) for Longarm Formation strata exposed in the southern part of the archipelago, but rocks on the central and northern islands were considered to be of somewhat deeper water origin. The diverse and abundant fauna suggests that the bulk of the Longarm Formation at Cumshewa and Long inlets accumulated at shelf depths (<200 m). Unfossiliferous shale and turbidite sandstone in the upper part of the formation at Long Inlet may reflect a continuation of the deepening trend during deposition in that area. The same trend may exist in Cumshewa Inlet.

Haggart et al. (1989) have suggested that the deeper-water shale noted at the top of the Longarm Formation section at Long Inlet might perhaps be gradational into the overlying sequence of turbidite sandstone and shale of the Skidegate member of the Haida Formation, of Cenomanian and younger age. In this model, deposition of the upper Longarm shale may span the Barremian, and parts of the Aptian and Albian as well. Thus, deposition in the deeper basinal areas of Long Inlet may have been continuous, while shoreline regions to the east experienced transgressive/regressive oscillations resulting in local unconformities.

Sutherland Brown (1968) suggested that Longarm Formation deposition occurred during a time of volcanic quiescence. Although volcanics may be associated with the formation in northern Graham Island, no definitive evidence of extensive volcanic rock accumulations was noted.

Sutherland Brown (1968) also suggested that as much as 1200 m of Longarm Formation exists in the Long Inlet area. However, this figure seems too high. A section of the formation approximately 200 m in thickness was measured near Young Point and includes all the Long Inlet faunal horizons noted to date. Assuming that the thickness of the overlying shale is approximately equal (250 m), the total estimated thickness (450 m) is somewhat less than half of Sutherland Brown's value. Perhaps Sutherland Brown considered that the extensive areas devoid of outcrop along the shore of the inlet southeast of Indian Cabin Creek represent covered Longarm Formation.

Although fossil dating of the various Longarm sections is still preliminary it appears that deposition of the preserved section in Long and Cumshewa inlets occurred during a single depositional cycle spanning the Hauterivian and Barremian, and possibly part of the Aptian as well. The sequence on northern Graham Island, however, suggests that Longarm Formation deposition in that region commenced in the Valanginian or possibly earlier.

CONCLUSIONS

1. Longarm Formation strata are widely exposed on the Queen Charlotte Islands.
2. Sedimentary structures and mollusc faunas in these rocks indicate that the Longarm Formation was deposited principally in shallow-marine (<200 m) environments.
3. Lithological successions at three study areas reflect a single depositional cycle. Although the basal beds of the formation are not always seen, fining-upward sequences are always noted.
4. Deposition in two of the studied sections appears to have occurred during the Hauterivian and Barremian and possibly Aptian as well. Exposures on northern Graham Island indicate an earlier age for the onset of deposition in that area, during the Valanginian or earlier.

ACKNOWLEDGMENTS

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The middle Cretaceous Haida Formation: a potential hydrocarbon reservoir in the Queen Charlotte Islands, British Columbia[1]

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Abstract

Petrographic examination of newly collected sandstone samples of the middle Cretaceous Haida Formation of the Queen Charlotte Islands, indicates hydrocarbon reservoir development. Increasing mineralogical and textural maturity, primarily quartz framework grain content and sorting, may be related to the Rennell Sound fold belt. Regionally, visual porosity increases in a southerly direction, with values exceeding 15 % observed at the head of Cumshewa Inlet. Improved reservoir characteristics and the blanket nature of the Haida sandstones combine to create a strong hydrocarbon objective in Hecate Strait.

Résumé

L'examen pétrographique d'échantillons fraîchement prélevés de la formation de Haida du Crétacé moyen des îles de la Reine-Charlotte indique la formation de réservoirs d'hydrocarbures. La maturité minéralogique et texturale croissante, surtout la granulométrie des grains de quartz du squelette, peut être associée à la zone de plissement de Rennell Sound. À l'échelle régionale, la porosité visible augmente dans la direction sud, et des valeurs dépassant 15 % ont été observées dans le fond de l'inlet Cumshewa. De meilleures caractéristiques de réservoir, ajoutées à la couverture que constituent les grès de Haida, font du détroit d'Hécate une cible de recherche d'hydrocarbures importante.

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INTRODUCTION

Newly collected sandstone samples from the basal member of the middle Cretaceous Haida Formation (Fig. 3) reveal a southerly increase in mineralogical and textural maturity. Increased quartz framework grain content and corresponding decrease of lithic and feldspathic components are coupled with increased porosity, providing the only unit yet discovered within the Cretaceous sequence of the Queen Charlotte Islands that has the potential to be a petroleum reservoir rock. This southerly increase in porosity was initially documented by Fogarassy and Barnes (1988a), and has been confirmed by petrographic and scanning electron microscope studies and fieldwork during the 1988 field season. Thus, the Haida Formation must be considered a strong secondary objective after the Tertiary Skonun Formation (Fogarassy and Barnes, 1988b) (Fig. 4).

PETROGRAPHY

The Haida Formation, deposited during a major middle Cretaceous marine transgression (Yagashita, 1985), is divided into three regionally mappable lithofacies (Fig. 3). The formation grades from fluvial and/or estuarine granule conglomerates and medium- to very coarse-grained arkosic sandstones of the basal Haida lithofacies to fine grained, argillaceous marine sandstones of the lower Haida sandstone lithofacies, and interbedded sandstones, siltstones and mudstones of the upper Haida lithofacies. Sutherland Brown (1968) briefly described the basal deposits of the Haida as '...exceptional in being relatively mature...' (p. 87) and Yagashita (1985) documented visual porosity in the lower part of the formation on the north shore of Cumshewa Inlet. Petrographic study of the basal Haida lithofacies reveals a distinctive suite of framework and cementing minerals.

Framework grains

Framework grains of the basal Haida lithofacies consist mainly of polycrystalline and monocrystalline quartz. Polycrystalline grains display ribbon textures and are best described as mylonites (Fig. 5A). These grains are generally monomineralic; similar quartz also occurs with plagioclase and potassium feldspar as plutonic rock fragments. Mylonitic quartz grains show an unusually high degree of sorting, rounding and sphericity; such textural maturity strongly

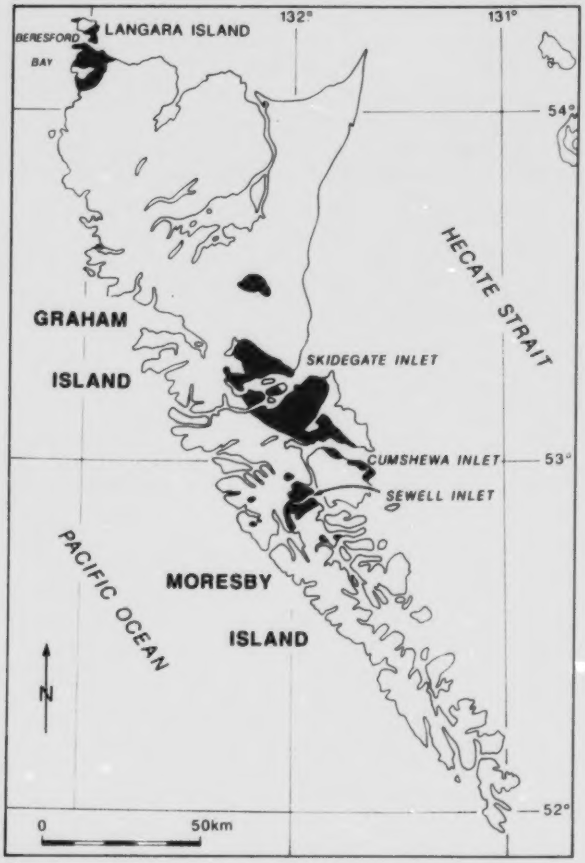


Figure 1. Middle to Upper Cretaceous outcrops and major physiographic features, Queen Charlotte Islands (adapted from Sutherland Brown, 1968).

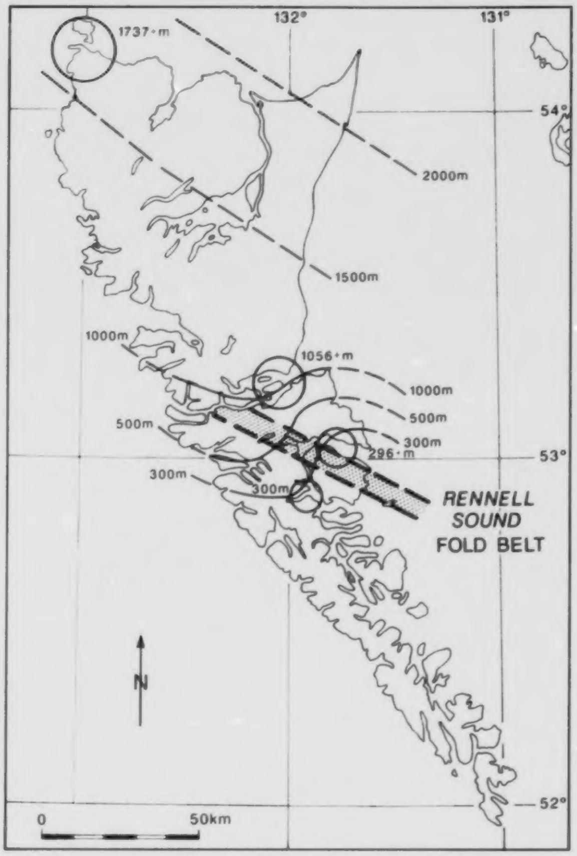


Figure 2. Isopach map of the Queen Charlotte Group and location of the Rennell Sound fold belt (adapted from Thompson, 1988).

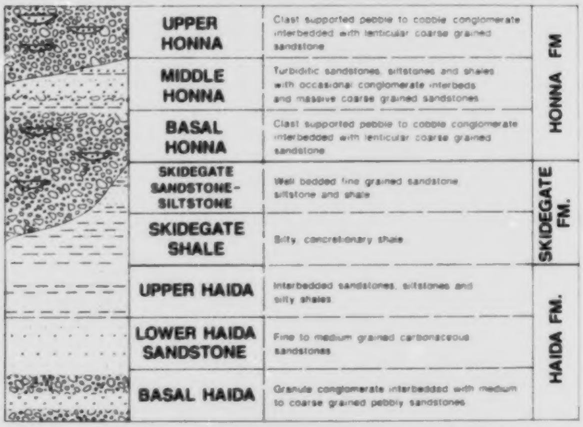
suggests recycling from Lower Cretaceous or Jurassic sedimentary strata. Thin sections of Jurassic plutonic rocks of Lyell Island, collected by R.G. Anderson, show mylonite textures similar to those observed in the basal Haida lithofacies.

Feldspars are generally less mature texturally than quartz, and occasionally display myrmekitic and micrographic intergrowths (Fig. 5B). Contrary to a recent petrographic study (Yagashita, 1985), orthoclase is relatively abundant, comprising 5-30% of framework grains. Orthoclase is an important component in the development of secondary porosity in the Basal Haida lithofacies (as well as in the rest of the Queen Charlotte Group). It commonly displays selective dissolution along cleavage planes (Fig. 5C). Plagioclase, although more abundant than orthoclase, is not as pervasively leached.

Quartz, plagioclase and orthoclase comprise about 60-95 % of framework grains in the basal Haida lithofacies. Lithic rock fragments are variable in composition and abundance. Rounded shale and argillite fragments, derived from the Kunga and Maude groups, account for the majority of lithic fragments. Trachytic volcanic rock fragments, derived from the Yakoun Group, occur in greater abundance in northerly sections. Varying amounts of organic matter, primarily carbonized plant material, may contribute to secondary porosity development observed in calcite cemented zones (Fogarassy and Barnes, 1988a). Detrital phyllosilicates, mainly biotite and muscovite, account for less than three percent of total framework grains. Biotite is generally partly chloritized and exhibits bending and warping of individual flakes caused by compaction. Muscovite is more abundant in southern exposures and generally correlates with increased quartz content.

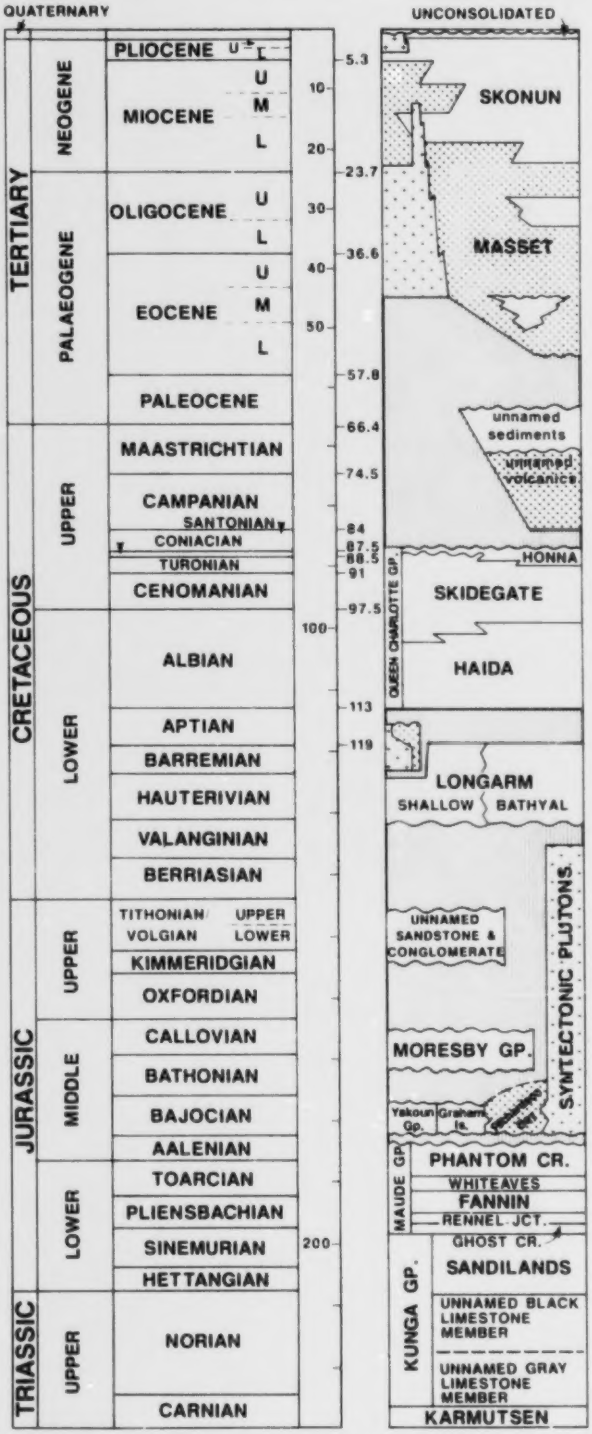
Cements and diagenetic history

Cement type is restricted to patchy, occasionally poikilitic, calcite and ferroan calcite and minor amounts of iron-rich chlorite. The diagenetic history of the basal Haida lithofacies in Skidegate and Cumshewa inlets involves the precipitation of carbonate cements, their subsequent dissolution and still later aluminosilicate framework grain dissolution.



UPPER HONNA	Clast supported pebble to cobble conglomerate interbedded with lenticular coarse grained sandstone	HONNA FM
MIDDLE HONNA	Turbiditic sandstones, siltstones and shales with occasional conglomerate interbeds and massive coarse grained sandstones	
BASAL HONNA	Clast supported pebble to cobble conglomerate interbedded with lenticular coarse grained sandstone	
SKIDEGATE SANDSTONE-SILTSTONE	Well bedded fine grained sandstone siltstone and shale	SKIDEGATE FM.
SKIDEGATE SHALE	Silty, concretionary shale	
UPPER HAIDA	Interbedded sandstones, siltstones and silty shales	HAIDA FM.
LOWER HAIDA SANDSTONE	Fine to medium grained carbonaceous sandstones	
BASAL HAIDA	Granule conglomerate interbedded with medium to coarse grained pebbly sandstones	

Figure 3. Queen Charlotte Group lithofacies chart (adapted from Yagashita, 1985, and Haggart, 1986).


QUATERNARY
UNCONSOLIDATED
TERTIARY
NEOGENE
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PLIOCENE
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PALEOCENE
CRETACEOUS
UPPER
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
LOWER
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
JURASSIC
UPPER
TITHONIAN
VOLGIAN
UPPER
LOWER
KIMMERIDGIAN
OXFORDIAN
MIDDLE
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
LOWER
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
TRIASSIC
UPPER
NORIAN
CARNIAN
10
20
30
40
50
100
200
5.3
23.7
36.6
57.8
66.4
74.5
84
87.5
88.5
91
97.5
113
119
SKONUN
MASSET
unnamed sediments
unnamed volcanics
HONNA
SKIDEGATE
HAIDA
QUEEN CHARLOTTE GP.
LONGARM
SHALLOW
BATHYAL
UNNAMED SANDSTONE & CONGLOMERATE
MORESBY GP.
SYNTECTONIC PLUTONS
Yakoun Gp.
Graham Is.
MAUDE GP.
PHANTOM CR.
WHITEAVES
FANNIN
RENNEL JCT.
GHOST CR.
KUNGA GP.
SANDILANDS
UNNAMED BLACK LIMESTONE MEMBER
UNNAMED GRAY LIMESTONE MEMBER
KARMUTSEN

Figure 4. Stratigraphic column for the Queen Charlotte Islands (after Cameron and Hamilton, 1988).

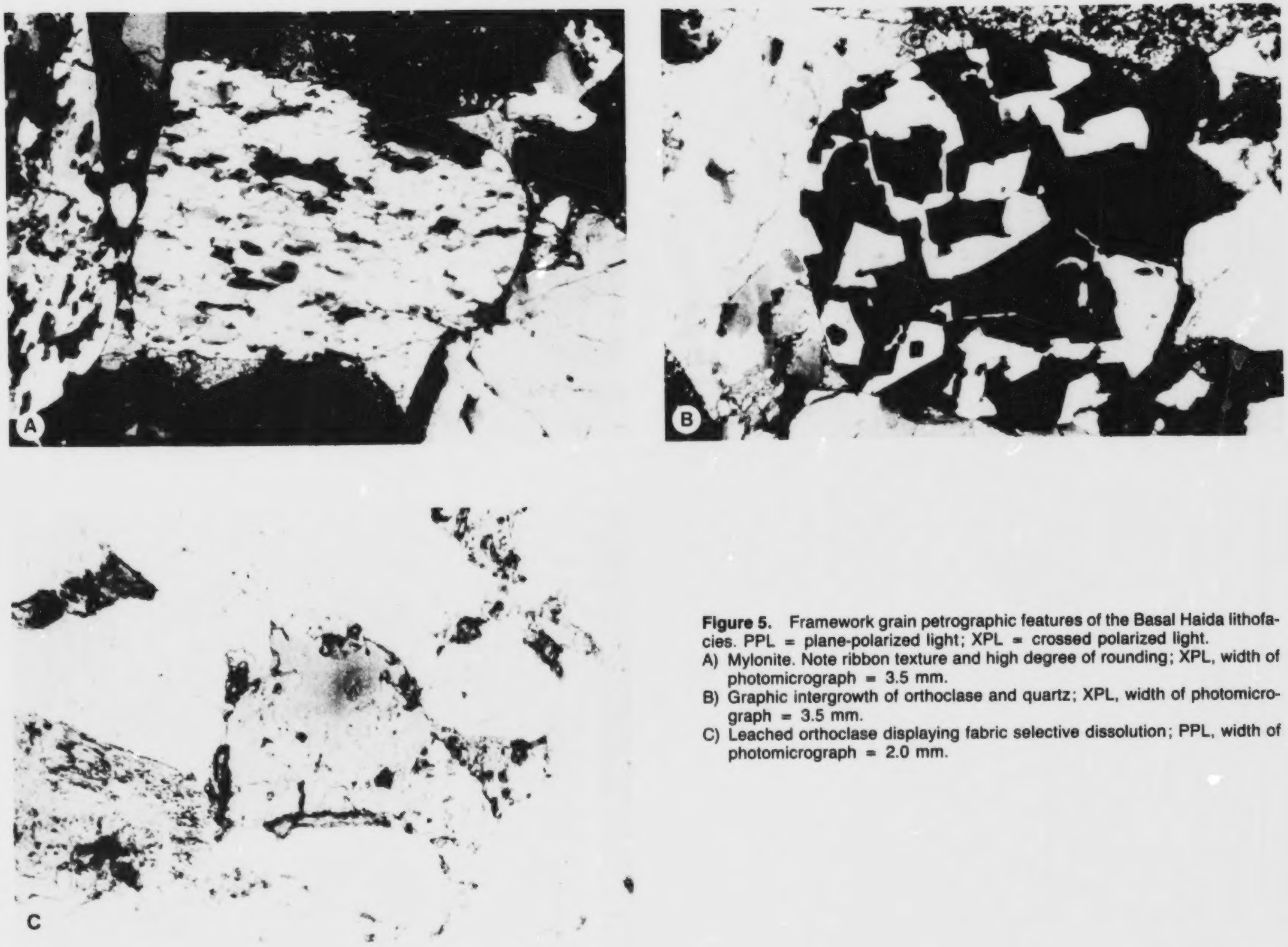

Figure 5. Framework grain petrographic features of the Basal Haida lithofacies. PPL = plane-polarized light; XPL = crossed polarized light.

A) Mylonite. Note ribbon texture and high degree of rounding; XPL, width of photomicrograph = 3.5 mm.

B) Graphic intergrowth of orthoclase and quartz; XPL, width of photomicrograph = 3.5 mm.

C) Leached orthoclase displaying fabric selective dissolution; PPL, width of photomicrograph = 2.0 mm.

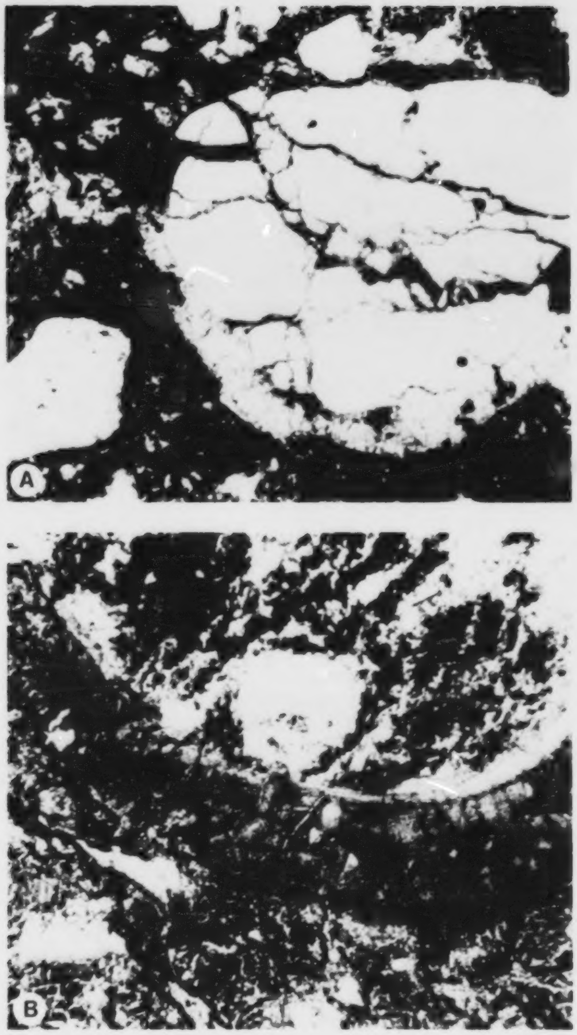

Figure 6. Cement petrographic features of the basal Haida lithofacies:

A) Exfoliation texture. Note puzzle-like arrangement of displaced fragments; PPL, width of thin section photomicrograph = 3.5 mm.

B) Calcite stalactite cement, a strong vadose zone indicator, is forming on a radiolarian bearing argillite rock fragment and displays six separate cementation episodes beginning with iron-free calcite and progressing to iron-rich calcite; PPL, width of photomicrograph = 3.5 mm.

Calcite cements

Basal Haida sediments in the Beresford Bay — Langara Island region are characterized by early cements. Complex cement zoning involving calcite and ferroan calcite indicates a variable diagenetic environment. Ferroan calcite is the most abundant carbonate cement observed. Framework grains often appear to "float" in calcareous beds and concretions, indicating early diagenesis. Growth of fibrous carbonate cements creates exfoliation textures (Fig. 6A), fracturing and separating framework grains. These displacive textures, typical of the Beresford Bay — Langara Island region, indicate an initial cementation episode under vadose conditions (Buczynski and Chafetz, 1987).

Well developed calcite and ferroan calcite microstalactitic (or gravity) cement also indicates formation in the vadose zone (Fig. 6B). Iron-free calcite commonly rims framework grains and predates ferroan calcite cementation. Outcrops to the south, in Skidegate and Cumshewa inlets, exhibit less pervasive carbonate cementation with nonferroan calcite dominating the carbonate assemblage. Vadose zone textural indicators are absent but may have not been preserved. Large compositional variations of intergranular calcite cements are observed in Cumshewa Inlet. The north shore of the inlet has very pure calcite cements whereas the south shore contains iron-rich, sparry calcite cements.

Stable carbon and oxygen isotope values from basal Haida cements show rapid changes, particularly in the Cumshewa Inlet region. Carbon isotope ratios on the north shore of Cumshewa Inlet are lighter than those on the south shore; similar but more subdued trends are seen in oxygen isotope ratios. More stable isotope data are being obtained to enable interpretation of the large isotope data variations observed in Cumshewa Inlet with respect to the diagenetic history of the Haida Formation.

Chlorite

Chlorite is the most abundant phyllosilicate in the basal Haida lithofacies. It is observed in numerous thin sections and is recognized by its distinctive green hue and pore-lining and pore-filling habit. Characteristic basal reflections (001), (002), (003) and (004) are present in all X-ray diffractograms. Ripidolite, an iron-rich member of the chlorite group, is the dominant species. (002) and (004) reflections are strong, whereas (001), (003) and (005) peaks are correspondingly weak. Relative intensity ratios of even versus odd basal reflections indicate iron-rich chlorites. Presence of iron-rich chlorite was also confirmed with the S.E.M./E.D.S.

Diagenetic history

Chlorites of the Basal Haida lithofacies are entirely diagenetic. Textural observations indicate chlorite formation occurred at an early stage of diagenesis, but after microstalactitic and concretionary calcite and ferroan calcite cementation. Diagenesis of aluminosilicates involves partial and complete leaching of framework grains. Textures indicating fabric selective dissolution are abundant, particularly in the Cumshewa Inlet region. Orthoclase, plagioclase and volcanic rock fragments were leached most heavily in strata with little carbonate cement. In the Beresford Bay — Langara Island region secondary porosity formed in feldspars is often filled with a second generation of ferroan calcite cement. Angular pores, corroded and embayed framework grains and enlarged pore throats in the basal Haida lithofacies indicate the former presence of interstitial carbonates.

Diagenetic history of the basal Haida sediments in the Beresford Bay — Langara Island region is more complex than southerly exposures; this is probably due to a more heterogeneous framework grain composition with a strong volcanic provenance.

CONCLUSION: PETROLEUM RESERVOIR POTENTIAL

The basal Haida lithofacies is a thin potential petroleum reservoir rock in the Queen Charlotte basin; reservoir characteristics improve in a southerly direction, with the best visual porosity occurring in outcrops bordering Hecate Strait and Cumshewa Inlet. Southerly increases in mineralogical and textural maturity may be related to the Rennell Sound fold belt; the continuation of the fold belt into the offshore enhances the hydrocarbon prospects of the Haida Formation. However, porosity is restricted to the thin basal Haida lithofacies, thus the formation must be considered a secondary target at best.

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Sedimentology and implications for hydrocarbon exploration of the "Hippa beds", Queen Charlotte Islands, British Columbia

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Higgs, R., Sedimentology and implications for hydrocarbon exploration of the "Hippa beds", Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 53-58, 1989.

Abstract

The "Hippa beds," known from a single outcrop on Hippa Island, comprise up to 200 m of conglomerate, sandstone and mudstone of uncertain age. These deposits lie unconformably beneath Tertiary Masset Formation volcanics. The existence of the Hippa beds demonstrates that rocks with petroleum-reservoir potential may occur, at no great depth, beneath the extensive Masset outcrop of adjacent Graham Island.

Three facies were recognized. Facies 1 consists of mudstone with 10-20 cm thick sandstone interbeds, interpreted as offshore lacustrine deposits. Facies 2 and 3 consist, respectively, of conglomerate with crude horizontal stratification, and trough cross-stratified coarse sandstone; these are interpreted as braided-stream deposits. Paleoflow was toward the southwest.

It is suggested that the Hippa beds are Tertiary or Late Cretaceous. The presence of conglomerate implies nearby synsedimentary uplift; this tectonic episode may be the same one responsible for the conglomeratic Honna Formation (Coniacian) of the Queen Charlotte Islands.

Résumé

Les « couches de Hippa », qu'on trouve dans un seul affleurement dans l'île Hippa, renferment jusqu'à 200 m de conglomérats, de grès et de mudstone, dont l'âge est incertain. Ces sédiments sont recouverts en discordance par des roches volcaniques de la formation tertiaire de Masset. L'existence des couches de Hippa est la preuve que des roches-réservoirs (pétrole) pourraient être présentes, à des faibles profondeurs, au-dessous de l'affleurement étendu de Masset dans l'île Graham voisine.

On a reconnu trois faciès. Le faciès 1 est constitué de mudstones renfermant des intercalations de grès de 10 à 20 cm d'épaisseur, qui seraient des dépôts lacustres situés au large. Les faciès 2 et 3 sont respectivement constitués de conglomérats dont la stratification horizontale est mal définie, et de grès grossiers de dépression à stratification oblique; ces faciès consisteraient en des dépôts de cours d'eau anastomosés. Le paléoécoulement se faisait vers le sud-ouest.

On pense que les couches de Hippa seraient du Tertiaire ou du Crétacé supérieur, en raison des relations observées sur le terrain et de leur composition clastique. La présence de conglomérats indique qu'il y a eu soulèvement synsédimentaire à proximité; cette phase tectonique serait la même que celle qui a donné naissance à la formation conglomératique de Honna (Coniacien) des îles de la Reine-Charlotte.

INTRODUCTION

Exposed on the south shore of Hippa Island, off the west coast of Graham Island (Fig. 1), are several tens of metres of conglomerate, sandstone and mudstone. These deposits, on which nothing has been published, were informally named the "Hippa Beds" in a brief description by McWhae (1986), who acknowledged an earlier (1971) confidential oil-company report on these rocks by J.W. Murray. In reference to the same deposits, the well history report of the Port Louis borehole (Fig. 1) mentions "Several hundred feet of pebbly sandstones and conglomerates ... exposed in the vicinity of south-eastern Hippa Island" (Union Oil Company of Canada Limited, 1971). The Hippa beds were apparently unknown to Sutherland Brown (1968), whose map shows only Masset Formation volcanics and Jurassic(?) plutonic rocks on Hippa Island.

It is important to study and date the Hippa beds because (1) they will help to elucidate the tectono-sedimentary history of the Queen Charlotte Islands, thereby giving insights into the hydrocarbon potential of the region (Thompson, 1988), and (2) they constitute a potential reservoir unit.

The author visited Hippa Island by helicopter on 1 July, 1988, and spent several hours examining the Hippa beds.

NATURE OF THE OUTCROP

The Hippa beds are exposed in a wave-cut platform and intervening sea stacks for about 1 km along the south shore of Hippa Island (Fig. 1). The easternmost sea stack, at UTM grid reference PQ 354322, is flat-topped and amenable to landing by helicopter. Progress on foot along the shore is difficult because the stacks are steep-sided and because the platform is strewn with drifted logs and with boulders fallen from the steep cliffs of Masset volcanics backing the beach. Access is easiest at low tide. A surge channel which crosses the foreshore at 349322 is impassable at mid-tide.

The Hippa beds are also exposed on an islet at 361315, about 1 km southeast of Hippa Island (Fig. 1; McWhae, 1986). A fly-past of this islet by helicopter revealed several metres of gently dipping sandstone, showing large-scale trough cross bedding. About 700 m to the west, at 353315, a seaweed-covered rock exposed at low tide consists of Hippa beds according to McWhae (1986).

STRUCTURE AND THICKNESS

The outcrop of the Hippa beds is dissected by faults. Structural dip is uniform within any one sea stack but can differ widely from one stack to the next. Dips range from 10-50°. No folds were seen.

The structural complexity and a lack of marker beds means that strata can seldom be correlated from one sea stack to the next; consequently the total thickness of the Hippa beds is uncertain. The taller stacks expose up to 30 m of strata; hence the Hippa beds are at least 30 m thick. The total exposed thickness is estimated at 50-200 m.

RELATIONSHIP TO THE MASSET FORMATION

The shore exposures of the Hippa beds lie at the foot of steep cliffs composed of Masset Formation volcanics. The volcanics at the cliff-base are rhyolite, dipping northwards at 30-50°. The rhyolite locally shows millimetre-scale flow banding.

The Masset Formation overlies the Hippa beds with angular unconformity (Fig. 2), in contrast to the "generally faulted" relationship inferred by McWhae (1986). The

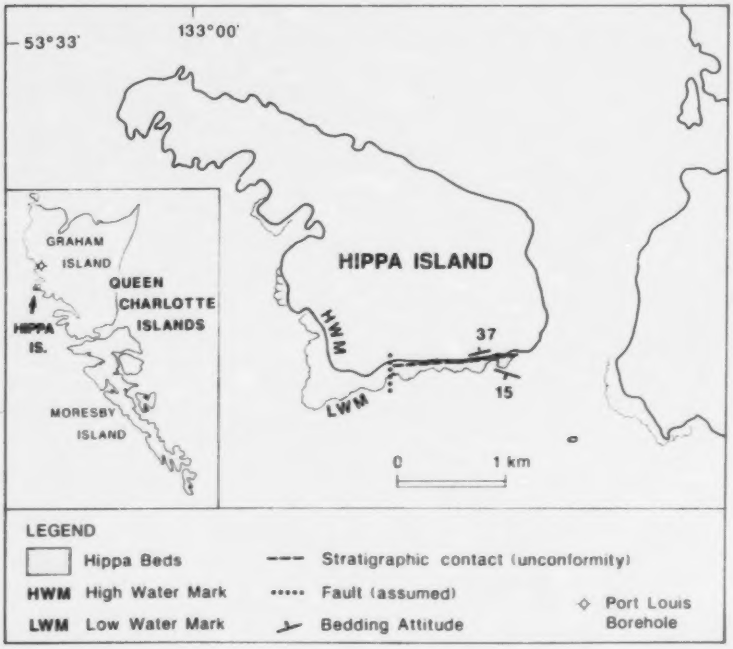

Figure 1. Map showing the outcrop of the Hippa beds. The outcrop essentially coincides with the foreshore, between high- and low-water marks. Not shown are numerous sea stacks on the foreshore, some of which are permanently emergent.

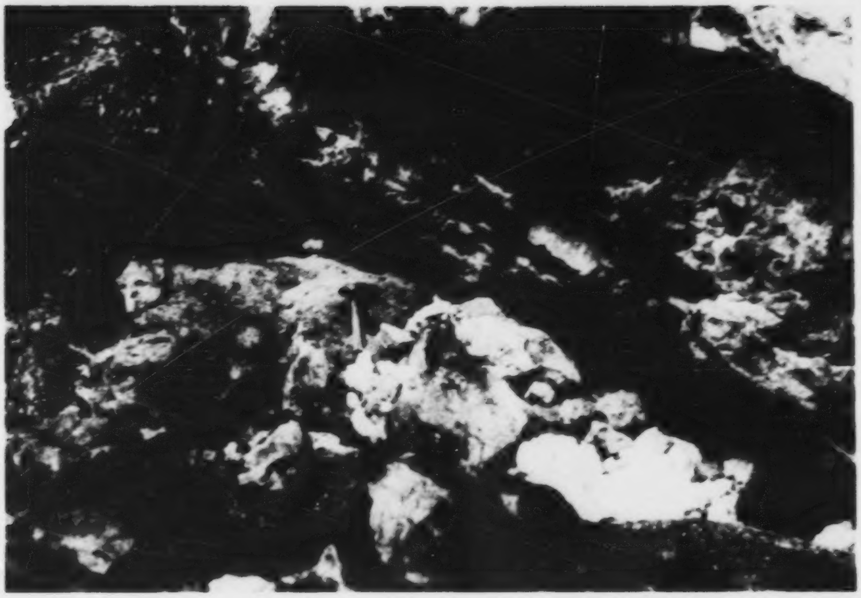

Figure 2. Angular unconformity between the Hippa beds and the Masset Formation. In this cliff-base exposure, pebbly sandstone of the Hippa beds (behind hammer, largely obscured by fallen boulders) is overlain by rhyolite of the Masset Formation. A crude stratification is visible in the rhyolite; the stratification runs from bottom right to top left, parallel to the (apparently planar) unconformity surface. Stratification in the underlying sandstone, revealed by pebble stringers, is clearly discordant. The contact shows no evidence of faulting, such as brecciation, slickensides or gouge.

unconformity is visible at several localities along the foreshore, generally within 5 m of the cliff-base; elsewhere the contact is obscured by logs and boulders. A 5 m thick mafic dyke, possibly a Masset feeder, cuts the Hippa beds in the foreshore immediately west of the sea stack at 354322.

FACIES

A section 19 m thick was measured in the easternmost sea stack (Figs. 3, 4). Thicker sections, up to 30 m, occur in other stacks, but these sections are inaccessible without ropes. Three facies are recognized in the Hippa beds; all occur in the measured section.

Facies 1: Interbedded mudstone and sandstone

Facies 1 is confined to the measured section (Fig. 3, interval 0-8 m), where it consists of silty mudstone with interbeds of fine grained sandstone. The sandstone beds, which comprise about 50 % of the interval, are mostly 10-20 cm thick, except in the top 2 m where they are thicker (20-30 cm). The sandstone beds are massive, lack obvious grading, and have diffuse upper and lower boundaries; these features may reflect extensive burrowing, although no discrete burrow forms were observed during a brief inspection. No body fossils were seen.

A subaqueous depositional environment is inferred, based on the lack of evidence for emergence (e.g. coals, paleosols, roots, desiccation cracks). The apparent lack of fossils may indicate nonmarine (fresh or brackish) conditions. The sandstone beds may represent flood deposits supplied to a lake floor or interdistributary bay by underflow.

Facies 2: Conglomerate with sandstone lenses

Facies 2 consists of pebble to small-cobble conglomerate containing lenticular sandstone beds up to 50 cm thick and 5 m long. The sandstone lenses comprise 10-30 % of the rock, and define a crude horizontal stratification (Figs. 3, 4). The conglomerate is clast-supported, with a medium- to coarse-sand matrix. Clasts are well rounded, with moderate to high sphericity; imbrication was noted locally. Two clast-counts, of 30 pebbles each, yielded an average composition of 80 % volcanics (including tuffs), 12 % quartz, 6 % granitoids and 1 % granule-conglomerate. The conspicuous white quartz pebbles (Fig. 4) are finely crystalline and may represent vein quartz; they are possibly derived from veined plutons, similar to the heavily veined (C.J. Hickson, pers. comm., 1988) pluton exposed nearby on the east coast of Hippa Island (Sutherland Brown, 1968). A piece of drifted fossil wood, 30 cm long and 10 cm in diameter, was found embedded in conglomerate at the measured-section locality.

The sandstone lenses are medium- to coarse-grained. Internally they are either massive or parallel-laminated, or else they comprise a single set of cross-laminae.

Facies 2 was deposited by high-energy currents, as indicated by the coarse grain size. The currents are unlikely to have been sediment gravity flows because Facies 2 lacks the sharp-based, variably graded beds characteristic of such flows (e.g. Lowe, 1982).

Facies 3: Cross-stratified sandstone

Facies 3 consists of medium- to coarse-grained sandstone and pebbly sandstone showing trough cross-stratification (Fig. 3, 4), tabular cross-stratification, and horizontal stratification. Individual troughs are up to 2 m thick and 5 m across. Tabular cross-sets range from 20 cm to 2 m thick. Facies 3 contains ellipsoidal calcareous concretions ranging from 5 cm to 1 m across (Fig. 4).

Facies 3 was deposited from traction by high-energy currents. The cross-stratification was formed by migration of large dunes and sandwaves.

PALEOCURRENTS

At the measured-section locality, trough cross-sets are visible in plan view (Fig. 4), thereby facilitating paleocurrent determination. The downcurrent axes of four separate troughs were measured, giving azimuths of 220, 240, 250 and 280°; the mean azimuth is 250°, indicating paleoflow toward the west-southwest. Correction for tilt is unnecessary because structural dip is low. Casual observation of conglomerate imbrication at the same locality likewise suggests paleoflow toward the southwest quadrant. Similarly, aerial observation of trough cross-sets on the islet southeast of Hippa Island indicates southwestward paleoflow.

FACIES ASSOCIATIONS AND DEPOSITIONAL ENVIRONMENT

Environmental interpretation is more reliable when facies are analyzed communaly, by considering facies associations and sequences (e.g. Reading, 1986). In the Hippa beds, it is not possible to erect facies associations because only three facies are known; these may or may not comprise a single facies association, which may or may not alternate with other, unexposed, facies associations. Identification of facies sequences is hindered by the fact that the longest continuous section in the Hippa beds is only about 30 m; detailed examination of the succession could conceivably reveal metre-scale sequences, but none was recognized in the present study.

Despite these difficulties, the three facies, taken communally, allow some tentative conclusions to be drawn. All three facies lack fossils and indications of emergence, pointing to a nonmarine, subaqueous depositional environment. Fluvial-channel deposition seems likely for facies 2 and 3, based on the coarse grain-size, crossbedding, and absence of features typical of sediment-gravity-flow deposits. The coarse grain-size suggests a braided, rather than meandering, river channel; this is supported by the strong resemblance between Facies 2 and "Facies Gm" of Miall (1977), which is typical of modern gravelly braided streams.

A lacustrine or interdistributary-bay setting was suggested above for Facies 1. In view of the association with braided-stream deposits, the lacustrine interpretation is the more likely. (Interdistributary bays, a component of classical deltas, are more likely to be associated with meandering streams.)

In the measured section, offshore-lacustrine sediments (Facies 1) are sharply overlain by fluvial-channel deposits (facies 2 and 3). Intervening lakeshore deposits, predictable from Walther's principle (e.g. Walker, 1984), are missing; they may have been removed by scouring associated with channel migration or incision. Facies 2 and 3 constitute a fining-upward sequence. This sequence may have formed either by channel migration, or by aggradation of the channel above the surrounding area, causing a progressive loss in stream competency due to the reduction of slope (Miall, 1977).

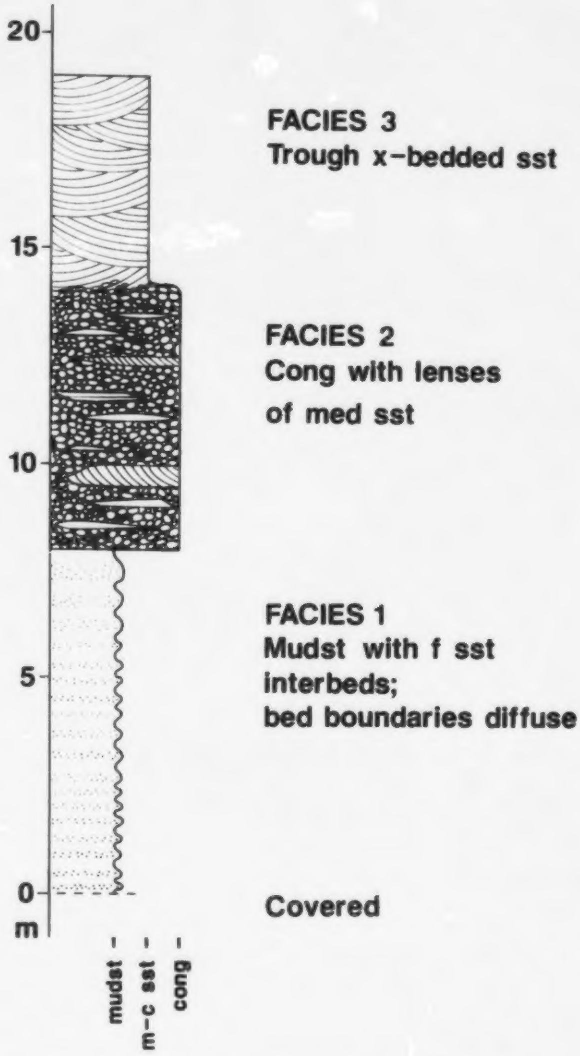

Figure 3. Graphic sedimentological log of a section measured in the sea stack at UTM grid reference 354322.

Figure 4. View of the measured-section locality, looking southwest. Conglomerate with discontinuous sandstone lenses (Facies 2) grades up into sandstone with large-scale trough cross-stratification (Facies 3). Note the conspicuous white (quartz) pebbles in Facies 2. Note also the scattered concretions (dark) in Facies 3, visible on the vertical face in the foreground.

AGE

The age of the Hippa beds is problematical. In terms of facies, the Hippa beds have no obvious affinity with any of the established formations of the Queen Charlotte Islands (Sutherland Brown, 1968). The lack of fossils and intercalated volcanics precludes direct dating.

The Hippa beds underlie Masset Formation volcanics and are therefore either pre- or intra-Masset in age; the former is considered more likely, in view of the angular unconformity, which implies a substantial tectonic interlude. Because the Masset Formation is Tertiary (Sutherland Brown, 1968; Hickson, 1988), the Hippa beds must be Tertiary or older. A late Cretaceous age is favoured by Union Oil Company of Canada Limited (1971), but their reasoning is unclear.

The base of the Hippa beds is not exposed, thus the lower age limit is difficult to constrain. If the quartz pebbles in the Hippa beds are derived from veined Jurassic(?) plutons, as suggested earlier, then the Hippa beds may be Jurassic or younger; this assumes that the veins are coeval with the plutons. Also pertinent to the age of the Hippa beds is the discovery, during the present study, of a single pebble of speckled, black-and-white granule conglomerate in a Hippa conglomerate unit. This distinctive granule conglomerate is characteristic of the Longarm Formation (Sutherland Brown, 1968), suggesting that the Hippa beds are post-Longarm. Since the Longarm is early Cretaceous (Valanginian-Barremian; Sutherland Brown, 1968), the Hippa beds are probably late Cretaceous or Tertiary.

The Hippa beds are possibly coeval with the Honna Formation of Coniacian age (Haggart, 1986), which is widely exposed in the central Queen Charlotte Islands region (Sutherland Brown, 1968). Both units are conglomeratic, and may reflect the same episode of syndepositional tectonism.

IMPLICATIONS FOR HYDROCARBON EXPLORATION

The Hippa beds are important to hydrocarbon exploration because they demonstrate that potential reservoir rocks could underlie much of the extensive volcanic (Masset) outcrop of western Graham Island (*see* Sutherland Brown, 1968, his Fig. 5), and that such rocks could be within easy reach of the drill. Both possibilities were further demonstrated by the Port Louis well, which drilled through 887 m of Masset volcanics into 577 m of nonmarine sandstone, shale and coal; the well bottomed in volcanics assigned to the Yakoun Formation (Middle Jurassic) by Union Oil Company of Canada Limited (1971). The Hippa beds and the Port Louis sediments could be coeval; it is interesting to note that both are situated on the axis of a regional north-south anticline mapped by Sutherland Brown (1968).

The Hippa beds have poor reservoir properties: porosity and permeability are low, probably due to occlusion of pores by the decomposition products of feldspars and volcanic grains. Beyond the known outcrop, however, there could be areas of better reservoir quality due to early migration of hydrocarbons, development of secondary porosity, or scarcity of volcanic rocks in the local source terrane.

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A new Late Cretaceous mollusc fauna from the Queen Charlotte Islands, British Columbia

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Abstract

Molluscs from marine shales apparently overlying the Honna Formation in the area of Skidegate Inlet, Queen Charlotte Islands, British Columbia, indicate a Late Santonian age. The species of ammonites and inoceramids present are previously known from the Santonian of Vancouver Island and northern California (Elongatum Zone). These shales are thus the youngest Cretaceous marine sedimentary strata yet recognized in the Queen Charlotte Islands and indicate that marine deposition continued in this region at least until the Late Santonian.

Résumé

*Des mollusques recueillis dans des argiles litées marines recouvrant apparemment la formation d'Honna dans la région de l'inlet Skidegate des îles de la Reine-Charlotte (Colombie-Britannique), indiquent qu'elles appartiennent à la fin du Santonien. Les ammonites et les inocéramidés présents ont déjà été reliés au Santonien sur l'île de Vancouver et en Californie septentrionale (zone d'*Eubostrychoceras elongatum*). Ces schistes argileux sont donc les plus jeunes couches de sédiments marins du Crétacé identifiées jusqu'à maintenant dans les îles de la Reine-Charlotte et indiquent que le dépôt en milieu marin plus profond s'est poursuivi dans cette région au moins jusqu'à la fin du Santonien.*

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INTRODUCTION

Molluscan faunas are relatively uncommon in the Upper Cretaceous of the Queen Charlotte Islands and, when present, are generally poorly preserved. Previous studies of molluscan fossils from the Upper Cretaceous of the Queen Charlotte Group have shown the existence of Cenomanian through Coniacian and possibly Santonian strata (Sutherland Brown, 1968; McLearn, 1972; Riccardi, 1981). Haggart (1986) summarized the molluscan collections made until 1985 and proposed a sequence of Upper Cretaceous ammonite and inoceramid bivalve faunal zones considered useful in local and international correlation.

In 1987, Higgs made several megafossil collections from the Skidegate Inlet area of the Queen Charlotte Islands, which suggested that a previously unrecognized Upper Cretaceous molluscan fauna might be present. The localities were revisited in 1988 by both authors and additional collections were made, resulting in an increase in the number of known species. The new fauna represents the latter part of the Santonian stage and is directly correlative with assemblages on Vancouver Island and in northern California.

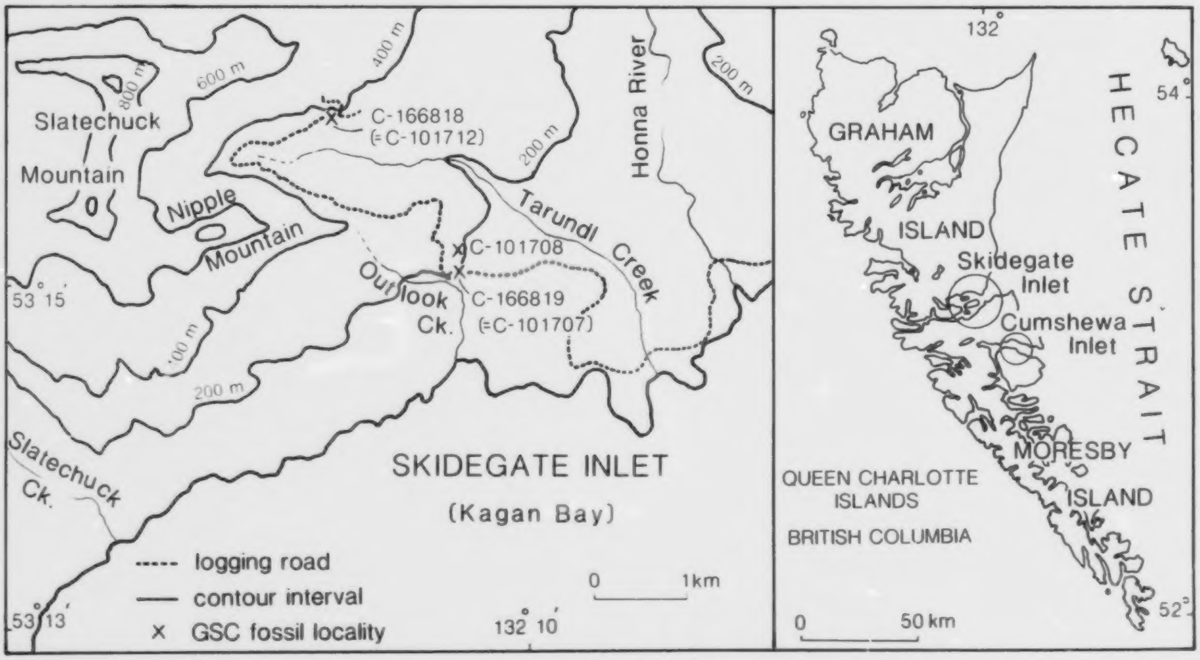
LOCALITIES

The fossil localities are situated on the eastern slope of Slatechuck Mountain, several kilometres north of Skidegate Inlet (Fig. 1). The outcrops are found at approximately the 400 m, 200 m, and 175 m contour levels on Slatechuck Mountain and represent the topographically highest exposures of Upper Cretaceous rocks in the Skidegate Inlet region.

The outcrops are composed of light to dark grey brittle shales, well bioturbated and containing abundant spheroidal to ellipsoidal calcareous concretions up to 30 cm in diameter. At other nearby localities, the shales are intruded by medium to coarse grained sandstone dykes, presumably injected upward from the underlying Honna Formation, which contains thick sandstones of similar grain size (Sutherland Brown, 1968). This relationship supports the new paleontological evidence that the Slatechuck Mountain shales are younger than the Honna.

Most fossils are preserved in calcareous concretions, and others usually exhibit a greater degree of calcareous cementation than the surrounding matrix, suggesting incipient concretion development. In general, the fossils appear to be oriented randomly throughout the concretions, although a few concretions contain discrete horizons of shell debris. The valves of some bivalves are still articulated, indicating little or no post- mortem transport. Pyritization of the shales is noted adjacent to some of the fossils.

The total thickness of shales in this area of Slatechuck Mountain is undeterminable due to the isolated nature of the outcrop. The localities visited are separated by nearly 200 m of topographic relief and as the structural dip seldom exceeds 30°, a significant thickness of strata could be inferred. Given the extensive faulting in areas adjacent to Slatechuck Mountain, however (Sutherland Brown, 1968, Fig. 5), the interpretation of stratigraphic continuity between the outcrops is not justified. At least 30 m of shale were noted in outcrop adjacent to GSC locality C-166818 (= C-101712).



Slatechuck Mountain
600 m
800 m
400 m
C-166818 (=C-101712)
200 m
Honna River
200 m
Nipple Mountain
Tarundl Creek
C-101708
C-166819 (=C-101707)
Outlook Ck.
53°15'
400 m
200 m
Slatechuck Ck.
SKIDEGATE INLET
(Kagan Bay)
----- logging road
—— contour interval
× GSC fossil locality
0 1km
53°13'
132°10'
132°
54°
GRAHAM ISLAND
Skidegate Inlet
Cumshewa Inlet
HECATE STRAIT
MORESBY ISLAND
QUEEN CHARLOTTE ISLANDS
BRITISH COLUMBIA
0 50 km
52°

Figure 1. Map of Slatechuck Mountain area (NTS 103 F/8) showing fossil localities.

The topographically lowest locality, GSC locality C-166819 (=C-101707), is situated in a quarry on the north side of the principal logging road servicing the eastern flank of Slatechuck Mountain. The following molluscs were collected or identified from this locality:

Hauericeras (Gardeniceras) gardeni (Baily, 1855)

Tetragonites cf. *popetensis* Yabe, 1903

Tetragonites? sp.

Neocrioceras cf. *spinigerum* (Jimbo, 1894)

Neophylloceras? sp. (juv.)

Hyphantoceras? sp.

Baculites sp. (juv.)

Gaudryceras striatum (Jimbo, 1894)

Inoceramus (juv.) cf. *naumanni* Yokoyama, 1890

I. cf. *japonicus* Nagao and Matsumoto, 1939 (not collected)

Inoceramus sp.

Propeamussium sp.

Glycymeris? sp.

Dentalium? sp. (juv.)

indeterminate juvenile bivalves and gastropods.

At GSC locality C-101708, a roadcut beside a spur leading north from the main logging road, the following bivalve was collected:

Inoceramus (Sphenoceramus) cf. *orientalis* Sokolov, 1914 *s.s.*

At the third and topographically highest locality, GSC locality C-166818 (= C-101712), a quarry, the following species were collected:

Polyptychoceras vancouverense (Whiteaves, 1879)

Gaudryceras striatum (Jimbo, 1894)

Eupachydiscus haradai (Jimbo, 1894)

Mesopuzosia sp.

Baculites sp.

Inoceramus cf. *naumanni*

Inoceramus sp.

Propeamussium sp.

Acila (Truncacila) sp.

Pholadomya subelongata Meek, 1857

Nanonavis cumshewaensis (Whiteaves, 1900)

wood with *Teredolites* borings.

The more important of these taxa are illustrated in Plate 1.

DISCUSSION

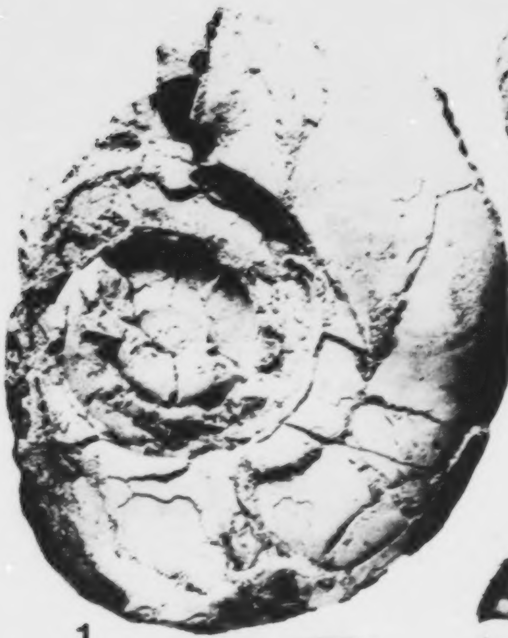
Biostratigraphy

The molluscan assemblages are very similar in composition to Santonian faunas in the lower part of the Nanaimo Group of Vancouver Island (Jeletzky, *in* Muller and Jeletzky, 1970; Haggart, in press) as well as the Chico and Redding formations of California (Matsumoto, 1959; Haggart, 1984a, b). The ammonites *Hauericeras (Gardeniceras) gardeni*, *Gaudryceras striatum*, *Polyptychoceras vancouverense*, and *Eupachydiscus haradai* are indicative of the Upper Santonian Elongatum faunal zone of the Nanaimo Group and all, excluding *H.* (*G.*) *gardeni*, are found at the same level in northern California, accompanied by *H.* (*G.*) *angustum* instead.

Two of the inoceramid species represented in the collections are based on poorly preserved fragments, but appear to be closely similar to *Inoceramus naumanni* and *I. (Sphenoceramus) orientalis*, also occurring in the Elongatum Zone of Vancouver Island and northern California (Haggart, 1984a). No inoceramid material in any of the lots from the Queen Charlotte Islands is comparable to the species group of *I. (Sphenoceramus) schmidti* Michael, of latest Santonian to earliest Campanian age in both southern British Columbia and northern California (Haggart, 1984a).

It is uncertain whether more than one faunal horizon is represented among the three collections from Slatechuck Mountain. *Inoceramus (S.) orientalis* occurs in both the Upper Santonian Elongatum and Schmidti zones of Vancouver Island, although it is less common in the lower part of the Elongatum Zone (Jeletzky, *in* Muller and Jeletzky, 1970). *Eupachydiscus haradai* is characteristic of the upper part of the Elongatum Zone of Vancouver Island and occurs together with *Polyptychoceras vancouverense* in Skidegate Inlet at GSC locality C-166818. Ward (1978) has suggested that *P. vancouverense* is restricted in the Nanaimo Group to beds older than those containing *E. haradai*, although he noted that the distribution of *P. vancouverense* appears to be controlled by ecological factors. As the range of *E. haradai* is well established in the Nanaimo Group, the occurrence of *P. vancouverense* in the Queen Charlotte Islands suggests that it may locally range up into the zone of *E. haradai* in western British Columbia and this is consistent with data (Haggart, unpublished) from California. Thus, the fossils from GSC locality C-166818 appear to be most closely related to those of the upper part of the Elongatum Zone of Vancouver Island and northern California, of Late Santonian age.

The collection from GSC locality C-166819 contains two heteromorph ammonite genera, *Neocrioceras* and *Hyphantoceras*, which have not previously been recognized in western Canada. *Hyphantoceras* is commonly found in strata ranging from Turonian to Santonian in the Pacific region, while *Neocrioceras* is typical of Santonian and Campanian deposits in many areas of the globe. *Neocrioceras spinigerum* is known from the Santonian of Japan (Matsumoto et al., 1986) and California (Haggart, unpublished).



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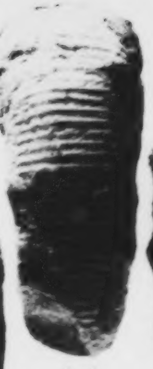

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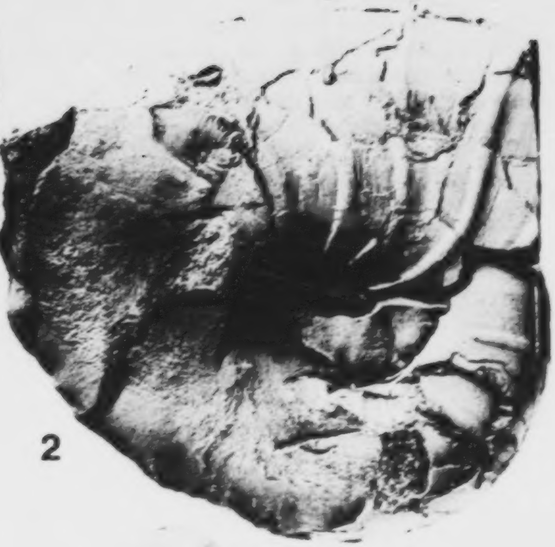

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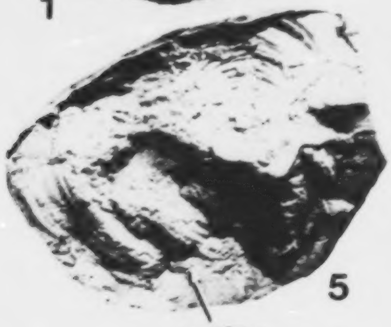

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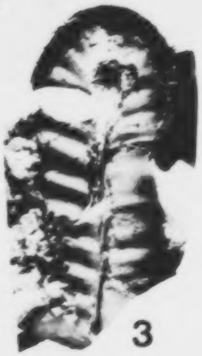

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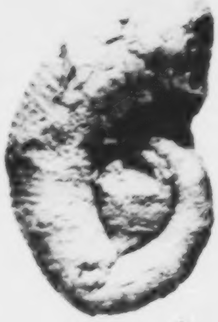

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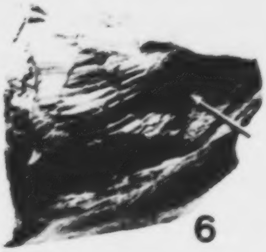

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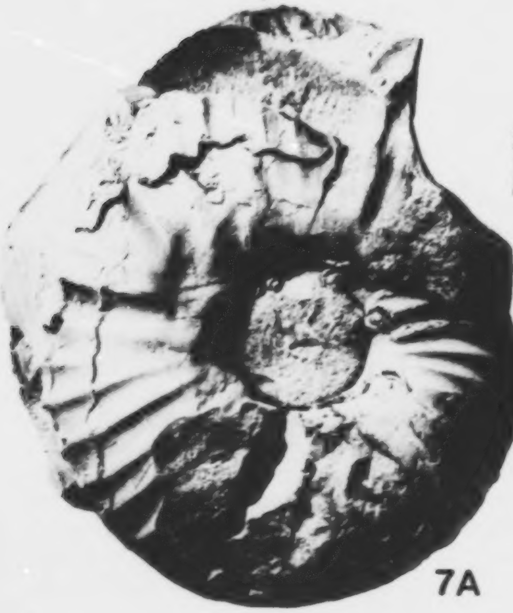

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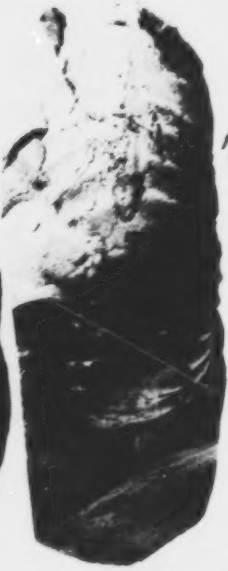

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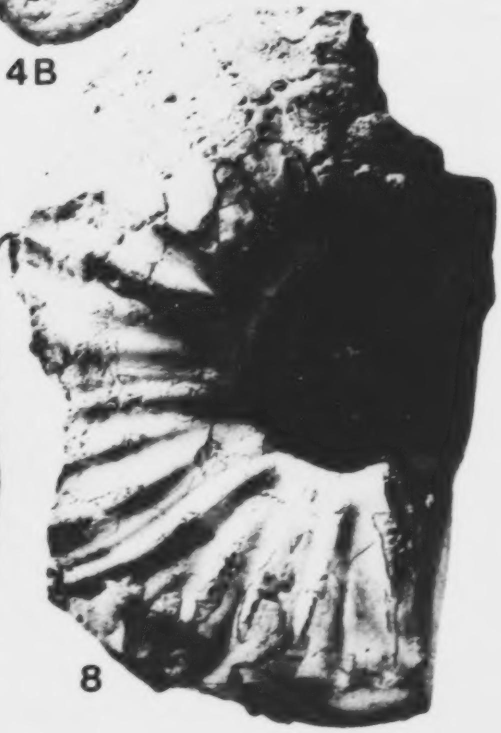

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PLATE 1

Figure 1. *Hauericeras (Gardeniceras) gardeni* (Baily, 1855)
GSC no. 94708 (GSC loc. C-166819). Lateral view of body chamber with partial mould of earlier whorls, x0.9 (GSC photo 204695-C).

Figure 2. *Gaudryceras striatum* (Jimbo, 1894)
GSC no. 94709 (GSC loc. C-166818). Lateral view, x1 (GSC photo 204695-E).

Figure 3. *Polyptychoceras vancouverense* (Whiteaves, 1879)
GSC no. 94710 (GSC loc. C-166818). Lateral view; most of the earlier shaft (leftmost) is preserved intact but the later shaft and elbow are moulds, x1 (GSC photo 205695-F).

Figure 4A, B. *Neocrioceras cf. spinigerum* (Jimbo, 1894)
GSC no. 94711 (GSC loc. C-101707). A, Ventral view, x1 (GSC photo 204674-E); B, Lateral view, x1 (GSC photo 204695-J).

Figures 5, 6. *Inoceramus (Sphenoceramus)* cf. *orientalis Sokolov*, 1914 *s.s.*
5. GSC no. 94712 (GSC loc. C-101708). Latex peel taken from mould, x1 (GSC photo 204695-4).
6. GSC no. 94713 (GSC loc. C-101708), x1 (GSC photo 204695-6). Figures 5 and 6 both show the marginally developed oblique folds (arrows) characteristic of the *orientalis* group.

Figures 7A, B, 8. *Eupachydiscus haradai* (Jimbo, 1894)
7A, B. GSC no. 94714 (GSC loc. C-166818). A, Lateral view showing damaged and repaired shell in umbilical region of later part of whorl, x1 (GSC photo 204695); B, Ventral view, x1 (GSC photo 204695-A).
8. GSC no. 94715 (GSC loc. C-166818). Lateral view, x0.6 (GSC photo 204695-B). Nodes do not occur on the central part of the flank.

Occurrences of both *Hyphantoceras* and *Neocrioceras spinigerum* in northern California are in the lower to mid-Santonian (Haggart, 1984b). It is thus possible that GSC locality C-166819 represents a slightly older horizon than GSC locality C-166818, which contains *E. haradai*.

The new Late Santonian mollusc fauna from the Queen Charlotte Islands is not known from the mainland of British Columbia. Late Santonian to Early Campanian ammonites and inoceramids occur in the Matanuska Valley region of southern Alaska (Jones, 1963) but these faunas, characterized by *I. (Sphenoceramus) schmidti* and other taxa, are slightly younger than those of the Queen Charlotte Islands.

Paleoecology

The diverse molluscan assemblages present at the Slatechuck Mountain localities indicate that the depositional environment of these strata was of shelf depth. Ammonites, especially heteromorphs, as well as most inoceramids are generally quite sparse in slope settings, submarine fans, and deep-basin regimes. Most of the taxa present in the collections are known from shallow-shelf deposits of northern California (Haggart, 1984b) and occur rarely, it at all, in equivalent deeper marine deposits of the Great Valley sequence. The occurrence of accumulations of randomly oriented fossils within concretions in the Slatechuck Mountain shales suggests post-mortem aggregation by currents. The undamaged nature of the shells and the presence of articulated specimens among the bivalves suggest minimal transportation, implying that the shell accumulations represent in situ winnowed lag deposits. The muddy nature of the sediments and the lack of sandy interbeds suggest an outer shelf setting.

Stratigraphic implications

Strata of the Queen Charlotte Group have been considered to range in age from Albian to Coniacian or possibly Santonian (Sutherland Brown, 1968; Haggart, 1986), and the Slatechuck Mountain fossil assemblages indicate the presence of younger Cretaceous strata. Prior to 1988, the youngest Cretaceous marine fossils known from the archipelago came from sandstones of the Honna Formation occurring at shoreline level in Kagan Bay, Skidegate Inlet (Riccardi, 1981; Haggart, 1986), and the Honna was thus considered to be the youngest lithological unit of the Queen Charlotte Group succession.

It is now evident that additional marine shales overlie the Honna Formation in Skidegate Inlet. These shales may represent the culmination of the fining upward trend noted in the Honna (Sutherland Brown, 1968). Haggart (1986) reported distinct shale successions in the upper part of the Honna Formation in Cumshewa Inlet, and recent field studies on the northern coast of Graham Island have shown the existence of thick shale accumulations in the uppermost Honna Formation there as well (Haggart, work in progress).

The upper age limit of the Slatechuck Mountain shale succession is presently unknown. Shouldice (1973) and Young (1981) reported nonmarine sedimentary strata of latest Cretaceous - Paleocene age from an exploration borehole in Hecate Strait, approximately 100 km southeast of the Skidegate Inlet area. The occurrence of Upper Santonian deposits in Skidegate Inlet indicates that Late Cretaceous deposition in the basin was temporally and geographically less restricted than previously considered. It is thus possible that additional Late Cretaceous horizons may be identified in the Queen Charlotte Islands region, culminating in a nonmarine phase in the latest Cretaceous or early Tertiary. Some support for the existence of nonmarine deposits of this age in the archipelago is given by the occurrence of coals and shales in the southwestern Skidegate Inlet area, apparently overlying the Honna Formation (Haggart et al., 1989).

SUMMARY

1. Molluscan fossils from a thick (>30 m) succession of shale indicate the presence of Upper Santonian strata in the Queen Charlotte Islands.
2. The ammonite and inoceramid species present in the collections are also known from Santonian strata of Vancouver Island and northern California. The fauna is not known from the mainland of British Columbia or southeastern Alaska.
3. The diversity of molluscan taxa indicates that the shales accumulated at shelf depths.
4. The Santonian shales are the youngest marine Cretaceous strata yet identified in the Queen Charlotte Islands and suggest that deposition in this region may have continued throughout the latter part of the Late Cretaceous.

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Stratigraphy and structure of Cretaceous strata, Long Inlet, Queen Charlotte Islands, British Columbia

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Abstract

The Cretaceous stratigraphic succession at Long Inlet, Queen Charlotte Islands, is particularly well exposed. The oldest rocks belong to the marine Lower Cretaceous (Hauterivian to Barremian) Longarm Formation, which is succeeded by the marine Upper Cretaceous Haida (Cenomanian to lower Turonian) and Honna (Coniacian to Santonian?) formations. Honna strata reflect rapid progradation of clastic depositional systems into the Long Inlet region and are conformably succeeded by a thick sequence of subaqueous volcanic debris flows, volcanic breccias, and subaerial volcanic flows. Structures within the Cretaceous section are dominated by northwest-trending megascopic folds, which are cut by two sets of faults exhibiting only minor offsets.

Résumé

La succession stratigraphique du Crétacé est particulièrement bien mise à nu à l'inlet Long dans les îles de la Reine-Charlotte. Les roches les plus anciennes appartiennent à la formation marine de Longarm du Crétacé inférieur (Hauterivien au Barrémien) et les formations marines d'Haida (Cénomanien au début du Turonien) et d'Honna (Coniacien au Santonien?) du Crétacé supérieur leur succèdent. Les couches de la formation d'Honna reflètent la propagation rapide des systèmes de sédiments clastiques dans la région de l'inlet Long et une épaisse séquence de coulées de débris volcaniques subaquatiques de brèches volcaniques et de coulées volcaniques subaériennes leur succède. À l'intérieur de la section crétacée, les structures sont dominées par des plis mégascopiques de direction nord-ouest qui sont recoupés par deux ensembles de failles ne présentant que des déplacements mineurs.

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INTRODUCTION

The Cretaceous stratigraphic succession at Long Inlet, Queen Charlotte Islands (Fig. 1), was extensively studied during the summer of 1988. Details of its biochronological succession, depositional environments, and subsequent structural history were obtained. New stratigraphic sections, which include many of the Cretaceous sedimentary rock units known in the Queen Charlotte Islands, were studied and a volcanic unit, of Late Cretaceous age, was noted in outcrop. These Cretaceous strata are deformed about megascopic northwest-trending folds, which may represent a northwest extension of the Rennell Sound Fold Belt of Thompson (1988). An understanding of the Cretaceous stratigraphic succession and structure is important in reconstructing the geological history of the Queen Charlotte Islands region, and is vital to any hydrocarbon assessment program.

STRATIGRAPHY

Longarm Formation

The oldest rocks recognized in the Long Inlet area are those of the Lower Cretaceous Longarm Formation. This name was introduced by Sutherland Brown (1968) for strata of Valanginian to Barremian age which occur at many localities in the Queen Charlotte Islands, but are especially well represented in the area of Long Inlet (formerly the Long Arm of Skidegate Inlet).

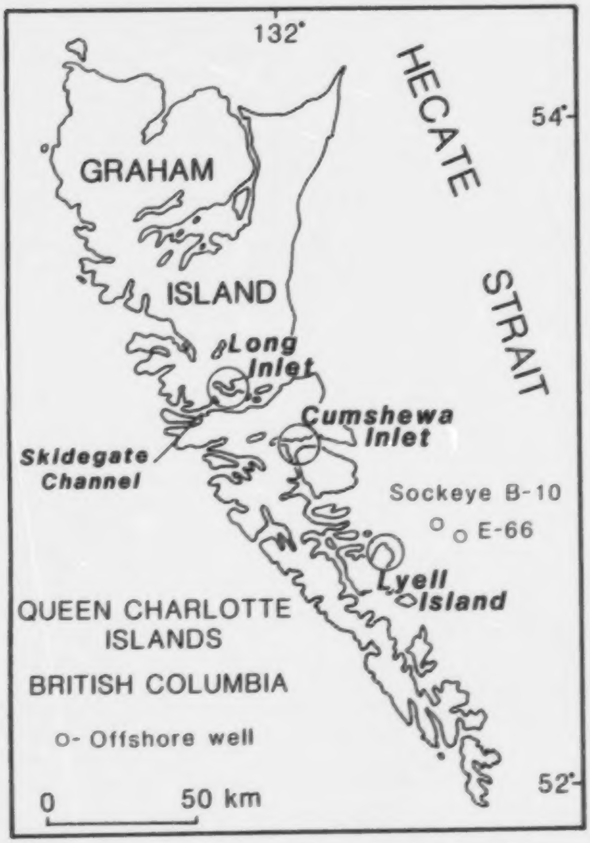

Figure 1. Location map showing areas discussed in text.

In the study area, Longarm Formation strata outcrop along the western shore of Long Inlet (Fig. 2). The exposures comprise a succession of northeast-dipping conglomerate, sandstone, siltstone, and shale. At several localities, felsic and mafic intrusions form sills or crosscut the strata at very low angles.

The base and uppermost parts of the formation have not yet been identified in the Long Inlet area. A distinctive granule conglomerate is found in the stratigraphically lower exposures along the inlet. This granule conglomerate is lithologically similar to those found at Cumshewa Inlet, 30 km to the southeast, where the Longarm Formation unconformably overlies the Lower Jurassic Sandilands Formation, and possibly the Middle Jurassic Yakoun Group. No Jurassic beds are known in the Long Inlet area; however, on the shores of western Skidegate Channel (Fig. 1), both the Sandilands Formation and the Yakoun Group are found (Sutherland Brown, 1968, Fig. 5; Lewis and Ross, 1988, Fig. 2).

It is now recognized that the Longarm Formation strata exposed in Long Inlet constitute a continuous fining-upward sequence that probably represents a single transgressive event (Haggart, 1989) of Hauterivian to at least Barremian age. The total thickness of Longarm Formation strata in the western Long Inlet area is unknown. One of us (J.H.) measured 193 m of section adjacent to Young Point. This section includes all the Lower Cretaceous fossil faunas recognized in the Long Inlet area. Shales which outcrop farther to the northwest, near the mouth of Lagins Creek, are not represented at Young Point. An additional 250 m of strata are estimated to overlie the section near Young Point.

Queen Charlotte Group

In previous interpretations of the stratigraphy of the Queen Charlotte Group, three major lithological units have been recognized: the Haida, Honna, and Skidegate formations. Sutherland Brown (1968) subdivided the Haida Formation into a lower or Sandstone member (primarily Albian in age), and an upper or Shale member (Cenomanian to early Turonian in age). The type locality and adjacent outcrops of the Skidegate Formation have been correlated with the Shale member of the Haida Formation using megafossils (Haggart, 1986; 1987; this report) and microfossils (Cameron and Hamilton, 1988, p. 223). Skidegate beds represent deeper water equivalents of the Haida Sandstone and Shale members.

Cameron and Hamilton (1988) proposed a revised Queen Charlotte Group nomenclature in which the term Haida Formation is limited to Sutherland Brown's Sandstone member and both the Haida Shale member and the Skidegate Formation are included in a greatly expanded Skidegate Formation. At its type locality, however, the Skidegate Formation consists of a succession of turbidite

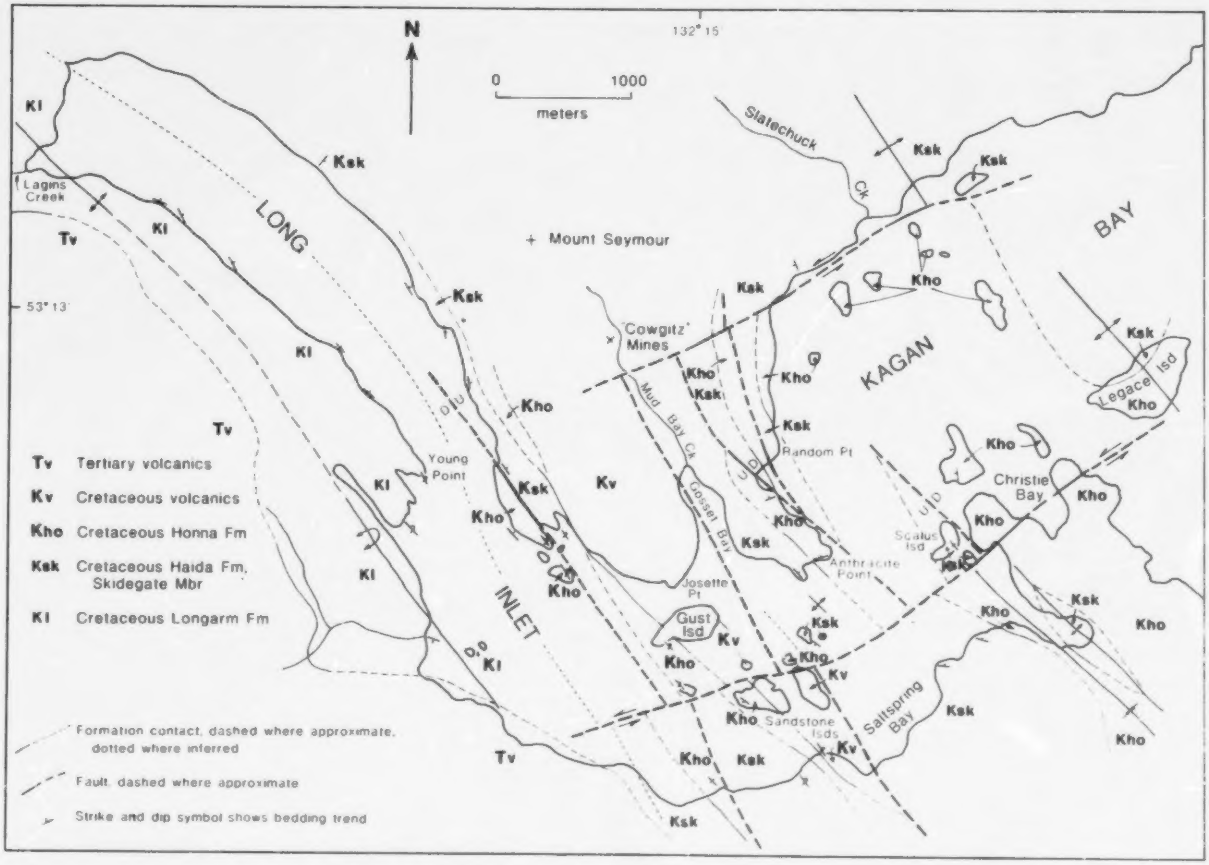
N
132° 15'
0
1000
meters
53° 13'
Lagins Creek
LONG
INLET
Slatechuck Ck
+ Mount Seymour
'Cowgitz' Mines
Mud Bay Ck
Gosset Bay
KAGAN
BAY
Legace Isd
Christie Bay
Random Pt
Scalus Isd
Anthracite Point
Young Point
Josette Pt
Gust Isd
Sandstone Isds
Saltspring Bay
U D
Tv
Kv
Kho
Ksk
Kl
Tv Tertiary volcanics
Kv Cretaceous volcanics
Kho Cretaceous Honna Fm
Ksk Cretaceous Haida Fm, Skidegate Mbr
Kl Cretaceous Longarm Fm
Formation contact, dashed where approximate, dotted where inferred
Fault, dashed where approximate
Strike and dip symbol shows bedding trend

Figure 2. Geological sketch map of the Long Inlet area, Queen Charlotte Islands.

sandstone and shale that is lithologically distinct (greater sandstone component) from the Haida Shale member; this distinction can be traced into Long Inlet. Moreover, our studies of the Queen Charlotte Group elsewhere in the islands (northwest coast of Graham Island; Cumshewa Inlet; Moresby Island) have shown that outcrops composed of the typical Skidegate lithology are relatively rare compared with those that can be assigned to the Shale member lithology. The Skidegate-type rocks are volumetrically of only minor importance in the archipelago. Thus we use the term Skidegate member as a separate, mappable unit of the Haida Formation, of equivalent age to the Shale member.

Haida Formation - Skidegate member

The Skidegate member outcrops extensively along the shoreline on the west and east sides of Mount Seymour, on Scalus Island and the more northerly of the Sandstone Islands, and on the south shore of Long Inlet from the west side of Saltspring Bay eastward to near Christie Bay (Fig. 2). The base of the unit has not been observed in the inlet. Sandstone and shale along the shoreline northwest of Josette Point were previously mapped as Honna Formation by Sutherland Brown (1968, Fig. 5). Individual outcrops generally exhibit several tens of metres of faulted and, typically, steeply dipping strata, separated by extensive covered intervals. We interpret the covered intervals as probably indicative of more shale-rich sections or fault zones, both of which weather preferentially. In general, the outcrops exhibit a west-northwest structural trend, essentially paralleling that of the older, Longarm Formation strata.

The Skidegate member is spectacularly displayed at several localities in the inlet (Fig. 3). Outcrops are predominantly thinly bedded turbidite sandstone and shale. In general the proportion of sandstone to shale is about 4:1, but at some localities the shale is equally represented. North of Anchor Cover, shale with small, 'potato-like', calcareous concretions occurs. This facies is considered transitional to the more shale- rich facies of the Shale member.

The ammonites *Turrilites* cf. *costatus* Lamarck and *Desmoceras (Pseudouhligella)* cf. *poronaicum* Yabe, as well as the bivalve *Mytiloides labiatus* (Schlotheim), were collected from the member at various localities (GSC localities C-166836, C-166841, C-166844, C-166845, C-166847) and indicate a Cenomanian to early Turonian age. The total thickness of the unit in Long Inlet is indeterminable, but along the coast northwest of Josette Point at least 50 m of Cenomanian or younger strata are exposed, succeeded by Honna Formation sandstone.

The Skidegate member is intruded by mafic (probably andesitic) dykes and sills of varying thickness. Locally, these intrusions are quite extensive.

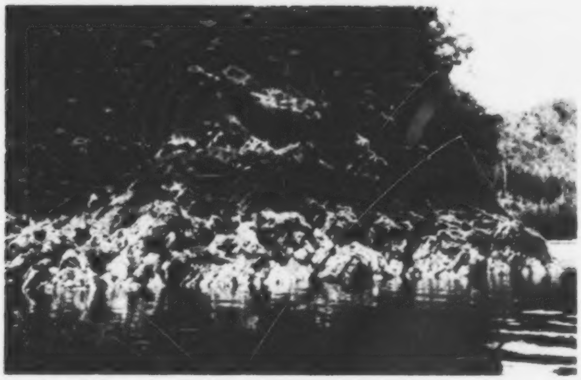

Figure 3. Steeply dipping, thinly bedded turbidite sandstone and shale of the Skidegate member of the Haida Formation exposed on an island 0.5 km south-southwest of Anthracite Point, Long Inlet (GSC photo 204713-N).

Honna Formation

The Honna Formation in the Long Inlet area comprises two distinct rock types. The lowermost consists of a thick sequence of medium to coarse grained grit and pebble- rich feldspathic sandstone with minor shale interbeds. These strata outcrop extensively on several islands in the southern portion of the inlet, and along the west flank of Mount Seymour, where at least 125 m of the sandstone (Fig. 4A, B) conformably overlie the shale and sandstone of the Skidegate member of the Haida Formation. Several sections of this sandstone lithofacies are exposed on the small islands south and west of Gust Island. A variety of sedimentary structures, including graded bedding in the sandstone/shale packages, flame structures, shale rip-up clasts, and ripple laminae horizons all suggest turbidite deposition for these strata.

The second distinctive lithofacies of the Honna Formation consists of cobble conglomerate, typical of the formation elsewhere in the Queen Charlotte Islands. This conglomerate was noted at numerous localities around the eastern margins of Long Inlet, especially in the vicinity of Christie Bay, north of Random Point, and on the many islands in western Kagan Bay. These conglomerates vary little from the description given by Sutherland Brown (1968) for the conglomerates occurring at the formation's type section at Lina Narrows.

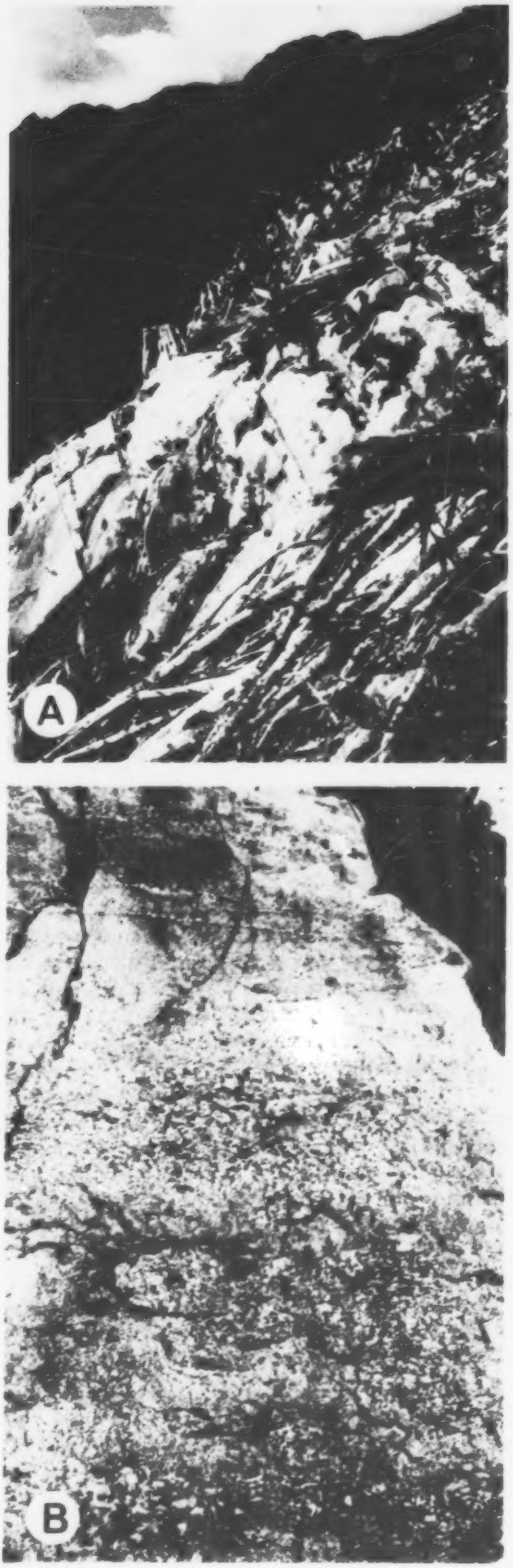

Figure 4. Lower, massive sandstone lithofacies of the Honna Formation, northeast shore of Long Inlet. **A**. Outcrop on west flank of Mount Seymour showing thick bedded nature of strata; note thin shale interbeds (GSC photo 204705-L). **B**. Closeup of individual sandstone bed showing pebble stringers (top) and grading of shale pebbles (bottom) in coarse grained feldspathic sandstone matrix (GSC photo 204705-M).

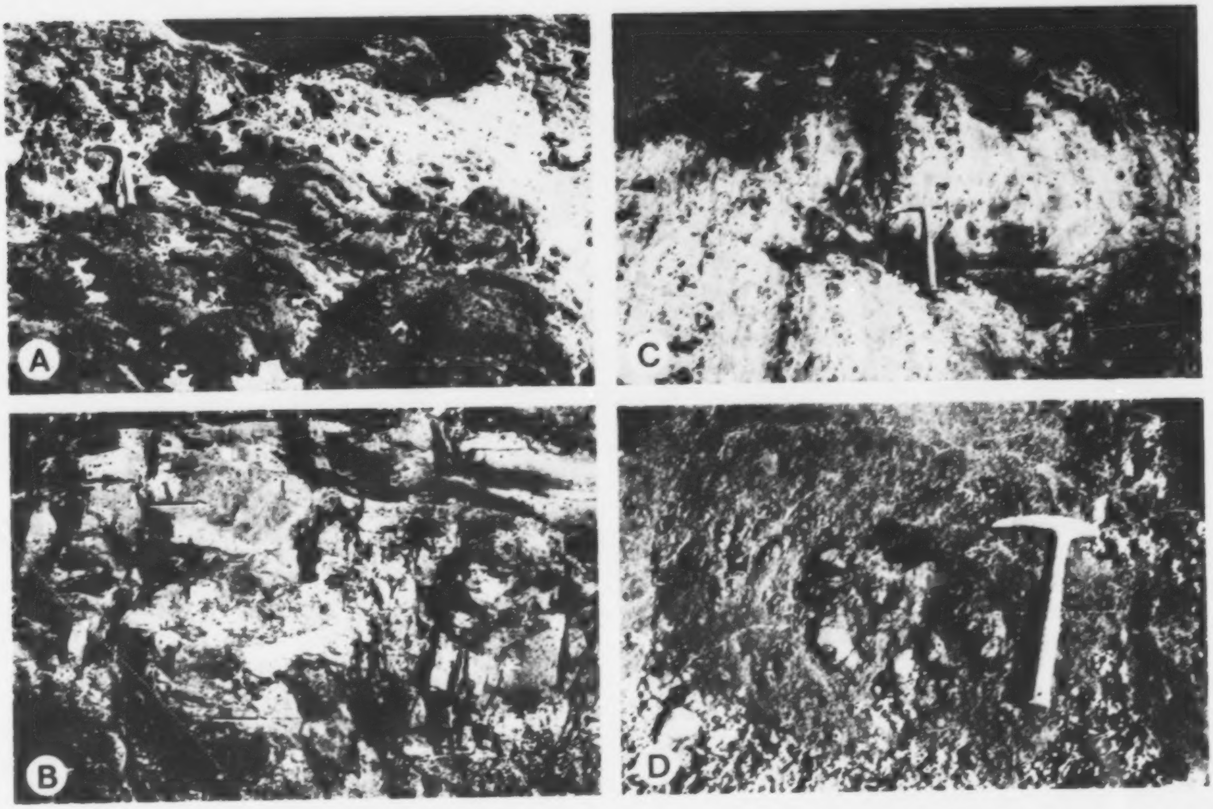

Figure 5. A-C: Basal portion of volcanic unit overlying the Honna Formation, Gust Island, Long Inlet. **A**. Irregular upper surface of mafic debris flow, overlain by coarse grained sandstone and conglomerate (GSC photo 204705-K). **B**. Closeup of flow breccia incorporating and overlain by coarse grained clastic (arrows); note numerous large plagioclase phenocrysts at lower right of photo; stratigraphic top is toward top of photo (GSC photo 204705-J). **C**. Conglomeratic sandstone overlying volcanic debris flows; the section is overturned and tops are to the right (GSC photo 204713-C). **D**. Scoriaceous deposit from central portion of Cretaceous volcanic unit (GSC photo 204713-D).

Honna Formation conglomerates are not known from the slopes of Slatechuck Mountain, north of Kagan Bay (R. Higgs, pers. comm., 1988). Along the north shore of the bay the conglomerates are limited to a single isolated block southwest of Slatechuck Creek. Honna conglomerates forming the north-trending ridge on the east side of Gosset Bay terminate abruptly east of Mount Seymour. This termination may be a fault contact.

Intrusive dykes commonly noted crosscutting the older shale and sandstone of the Haida Formation are rare in outcrops of the Honna Formation.

Although no fossil control was obtained for the Honna Formation in Long Inlet, nearby exposures in Skidegate Inlet are of Coniacian to Santonian age (Riccardi, 1981; Haggart, 1986). Honna strata are always noted overlying Skidegate member shale and sandstone of Cenomanian to early Turonian age in Long Inlet and the same relationship occurs at most localities in Skidegate Inlet and other areas of the Queen Charlotte Islands (Haggart, 1986; in prep.). It is not known whether this relationship reflects a regional hiatus.

Cretaceous volcanics

A sequence of mafic volcanic debris flows, scoria, and massive flows conformably overlies and interfingers with the Honna succession in Long Inlet. The best exposures of this volcanic succession are found in the vicinity of Josette Point, on the southwest side of Gust Island, and along the southwest shoreline of Saltspring Bay. The volcanics were previously mapped as a faulted exposure of the Masset Formation by Sutherland Brown (1968), but their conformable and interbedded contact with Honna Formation strata, and their presently overturned configuration make this interpretation unlikely.

The volcanic unit varies in thickness laterally. The greatest thickness observed is at Josette Point where approximately 700 to 800 m of the unit are exposed. An interbedded basal contact with the underlying Honna Formation is preserved on Gust Island and west of Saltspring Bay. The upper contact is not exposed.

Many of the volcanic rocks throughout this sequence are characterized by a content of 1 to 5 per cent euhedral plagioclase phenocrysts up to 5 mm in length. Pyroxene also occurs as a phenocryst phase and euhedral crystals up to 3 mm in length were noted in one flow. The matrix is pervasively altered and greenish to purplish in hand specimen.

The earliest indication of volcanism in the region is marked by subaqueous volcanic debris flows in the upper part of the Honna Formation. On Gust Island they are particularly well displayed in a continuous section. The lower, 115 m thick succession of sandstone and conglomeratic sandstone in this section is correlated with the Honna Formation on the basis of 1) lithological similarity to conglomerate and sandstone on-strike to the northwest and also the east — beds which conformably overlie early Turonian shale and sanstone; 2) the deeper water aspect of the beds as indicated by the abundance of sedimentary structures characteristic of turbidite deposition and the absence of any molluscan fossils; and 3) the presence of well rounded granitic cobbles within the conglomerates.

The first volcanic debris flows noted in the Gust Island section occur as a series, 5 to 15 m in thickness, within the uppermost part of the Honna Formation. These flows are poorly sorted, show no sedimentary structures, and are composed predominantly of porphyritic clasts (Fig. 5A). In the oldest flows, unlithified sands and silts of the underlying Honna Formation sequence are incorporated between blocks within the unit (Fig. 5B). This basal debris flow is succeeded by a 10 m thick section of medium to thick bedded sandstone and conglomerate (Fig. 5C), which in turn is overlain by the remainder of the volcanic succession. At all other localities studied the volcanic unit lacks the basal sandstone and conglomerate layer.

Overlying the basal volcanic debris flow and sedimentary rock succession on Gust Island is a thick section of scoria (Fig. 5D), flow breccias, and massive flows. The scoriaceous nature, and lack of sediments and quench features, indicate that the massive flows were deposited subaerially. The individual lithotypes occur in units of varying thickness with irregular contacts and little lateral continuity. At some localities, however, distinct flow units with intraflow breccias and amygdaloidal margins can be delineated and their contacts are parallel to bedding in the underlying Honna Formation.

Along the west shore of Gosset Bay, but absent at other localities, a less altered section of massive subaerial lava flows forms the uppermost exposures. These rocks can be distinguished from the underlying flows by the lack of abundant plagioclase phenocrysts and presence of small (1 mm) pyroxene phenocrysts set in an aphanitic dark grey groundmass. Within this section 10 to 20 m of massive flows are succeeded by a short interval of volanic breccia. This volcanic breccia is secondary in origin and can be distinguished from the underlying breccia because it contains both sedimentary and volcanic clasts.

Volcanic rocks have not previously been noted in outcrops of the Cretaceous Queen Charlotte Group. Prior to this study, volcanic rocks of the Queen Charlotte Islands were assigned to either the Tertiary Masset, Jurassic Yakoun, or Triassic Karmutsen formations, or minor flows within the Lower Cretaceous Longarm Formation. The volcanic rocks of the Long Inlet area cannot be correlated with any of the previously described units because of their conformable and interbedded relationship with the underlying sedimentary rocks of the Honna Formation.

Uppermost Cretaceous(?) sedimentary rocks

Coal occurs as float at approximately the 150 m elevation on the southeast flank of Mount Seymour, in the drainage basin of Mud Bay Creek. Coal deposits in Mud Bay Creek were exploited in the last century and several shafts were sunk, collectively referred to as the 'Cowgitz' workings, but the mines closed shortly thereafter. Although the actual workings were not located in 1988, coal float samples collected from the vicinity were commonly associated with shale lithotypes suggesting the coals occur in a shale succession. The literature on the coals (see Clapp, 1914) notes the occurrence of shales in the mine workings.

The precise stratigraphic position of these coals is uncertain, but Sutherland Brown (1968, p. 177, Fig. 5) suggested that they might be of either Jurassic or Cretaceous age. We suggest here that the coals might represent a new cycle of Upper Cretaceous sedimentation; if so, they may be approximately coeval with nonmarine sedimentary strata of latest Cretaceous-Paleocene age recognized in the subsurface of Hecate Strait (Shouldice, 1973; Young, 1981, p. 81, Fig. 17). In support of this interpretation, Haggart and Higgs (1989) have identified a new, upper Santonian ammonite assemblage from the Skidegate Inlet area. The fossils occur in a marine shale succession high on the flank of Slatechuck Mountain, several kilometres northeast of Mount Seymour. Thus, there is a possibility that additional Upper Cretaceous deposits exist in this region.

STRUCTURE

The Long Inlet area is characterized by consistent northwest trends of both structures and regional bedding. Earliest megascopic structures comprise northwest-trending, upright and locally overturned folds. A major anticline of this type lies parallel to and just west of the western shore of Long Inlet; most of the strata referred to in this report lie on the steeply dipping to overturned east-facing limb of this structure (Fig. 2). Folds of similar age, but lesser amplitude, occur in the eastern portion of the study area (Kagan Bay).

Two sets of steeply dipping 'map-scale' faults cut these early folds. The first set includes all faults striking northwestward; these are found at several localities in Long Inlet and were originally mapped by Sutherland Brown (1968) as components of his Rennell Sound Fault Zone. Despite the fact that they bound different stratigraphic units, these faults have only minor dip-slip offsets in Long Inlet, and are not observed in Skidegate Channel, only 5 km to the south (Lewis and Ross, 1988). The second and younger set of faults strikes from 055 to 070° through Long Inlet into Kagan Bay. These faults are inferred, on the basis of offset stratigraphic contacts and structures, to accommodate only minor left-lateral offsets.

Minor structures related to the megascopic structures are most common in shales. Low-angle thrust faults and drag folds are associated with the megascopic folds and probably developed as space-accommodating features. Strong pencil lineations occur parallel to fold axes, and locally developed cleavages are oriented parallel to axial planes; both are believed to be related to the early folding event. Internal deformation in coarser clastic and volcanic lithotypes is limited to steeply dipping fracture surfaces with minor offsets, and cannot be related to specific megascopic structures.

DISCUSSION

Long Inlet is an important locality for understanding the depositional and geological history of the Cretaceous succession in the Queen Charlotte Islands. The stratigraphy, as seen here, constrains interpretations of subsequent deformational events.

The contact of the Haida Formation with the underlying Longarm Formation was not observed in Long Inlet and the lower or Sandstone member of the Haida Formation is absent. Elsewhere in the Queen Charlotte Islands, the basal transgressive phase of the Haida is of earliest Albian age (McLearn, 1972; Sutherland Brown, 1968). As the youngest known Longarm Formation beds in Long Inlet are marine shales of Barremian and, possibly, Aptian age, they may be transitional to the shales and turbidite deposits of the Skidegate member. Thus, deposition in the deeper parts of the basin (i.e., the Long Inlet area) may have been continuous during the Aptian, although fossil evidence for this is lacking.

The distinctive feldspathic sandstone lithology present in the basal portion of the Honna Formation in Long Inlet has not previously been noted. Sedimentary structures in these rocks are indicative of turbidite deposition in a submarine fan setting, probably on the upper fan adjacent to the fan channel. Locally, the Honna sandstones thicken and thin laterally, even pinching out, consistent with an upper fan interpretation. This model supports the interpretation of the Skidegate member as a deep-marine distal turbidite succession and indicates fan progradation into the region of Long Inlet after the early Turonian. Several workers (Yagishita, 1985; Higgs, in press) have postulated an eastern source for the Honna Formation. Subaerial volcanic rocks conformably overlying the Honna Formation indicate that fan progradation resulted in rapid shallowing of the basin during Honna time.

Cretaceous volcanism in the Queen Charlotte Islands region has previously been inferred from K-Ar dates for samples from offshore wells in Hecate Strait. Young (1981) suggested that dates of 72 Ma and 84 Ma for volcanic rocks from the Sockeye B-10 well may represent an early phase of Masset volcanism and that the 118 Ma and 165 Ma dates from the Sockeye E-66 well represent mid-Jurassic Yakoun volcanics.

Cameron and Hamilton (1988) inferred that the volcanic rocks dated at 118 Ma represent a previously unrecognized volcanic event of Barremian-Aptian age. A volcanic conglomerate facies on Lyell Island has also been noted by them (*ibid.*) and was used as corroborative evidence for this event, although the dating of those rocks is presently uncertain. Likewise, they considered that the volcanic rocks dated as 72 Ma and 84 Ma represent yet another event (op. cit.).

Hickson (1988; 1989) has noted, however, that the Masset Formation is more restricted in age and distribution than previously thought. Thus, Young's (1981) interpretation that volcanic rocks dated at 72 to 84 Ma in the B-10 well are an early stage of Masset development appears untenable. Moreover, the K-Ar dates from the offshore wells are of minimum reliability, because of alteration and possible contamination (Young, 1981). The discovery of outcrops of Cretaceous volcanic rocks in Long Inlet is thus the first definite evidence of a Late Cretaceous volcanic event in the Queen Charlotte Islands region. Thin sections of sidewall cores from the volcanic intervals intersected by the offshore wells have been prepared and are currently undergoing detailed study to attempt lithological correlation with sections of known age (Hickson, in prep.).

SUMMARY AND CONCLUSIONS

1. The Queen Charlotte Islands Cretaceous stratigraphic succession, with the exception of the Haida Sandstone member, is particularly well represented in the Long Inlet area of western Skidegate Inlet.
2. 450 m of Longarm strata occur in Long Inlet, representing one depositional cycle of Hauterivian to at least Barremian age.
3. The base of the Cenomanian to early Turonian Skidegate member of the Haida Formation has not been seen in the Long Inlet area. It is possible that a depositional contact between the Haida Formation and the underlying Longarm Formation occurs in the central part of the inlet.
4. Two distinct lithofacies occur within the Upper Cretaceous Honna Formation: a thick lower succession of massive feldspathic sandstone and an upper unit of cobble conglomerate typical of the Honna Formation elsewhere in the Queen Charlotte Islands. A composite thickness in Long Inlet probably exceeds 150 m.
5. A thick succession of mafic volcanic debris flows, scoria, and flow breccias conformably overlies and is interbedded with the Honna Formation in Long Inlet. This unit may have correlatives elsewhere in the Queen Charlotte Islands and in the subsurface of Hecate Strait.
6. Structures in the Cretaceous rocks are dominated by northwest-trending megascopic folds, which are cut by two sets of faults showing only minor offsets.

ACKNOWLEDGMENTS

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An update on structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Columbia[1]

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Hickson, C.J., An update on structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Colmbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 73-79, 1989

Abstract

The Masset Formation is a Late Oligocene to Late Miocene calc-alkaline suite of volcanic rocks that underlies much of Graham Island. Rock compositions range from basalt to rhyolite; the principal phenocryst phase is feldspar. Thick rhyolite flows, coring hills inland of the west coast, may represent vent areas from which volcanic products and sediments were shed east and west. Evidence of steep north-trending faults was found, but otherwise there is little indication of structural complexity within the formation. Attitudes of layered rocks represent primary slopes of constructional volcanic landforms.

Older volcanic rocks were found intercalated within the Honna and Haida formations. These volcanic rocks contain hornblende phenocrysts which are not found in the Masset Formation.

Résumé

La formation de Masset, une série calco-alcaline de roches volcaniques dont l'âge s'étend de l'Oligocène supérieur au Micoène supérieur, constitue la majeur partie des terrains de l'île Graham. La composition des roches varie des basaltes aux rhyolites; la principale phase de phénocristal est le feldspath. Des coulées épaisses de rhyolite, constituant le noyau des collines dans l'intérieur des terres de la côte ouest, seraient des cheminées d'éruption desquelles des produits volcaniques et des sédiments se seraient déversés à l'est et à l'ouest. L'existence de failles abruptes, de directon nord, a été prouvée, mais en dehors de ce phénomène tectonique, la formation présente peu d'indications d'une complexité structurale. Les attitudes des roches stratifiées correspondent aux pentes primaires de formes volcaniques de construction.

On a trouvé des roches volcaniques plus anciennes intercalées au sein des formations de Honna et de Haida. Ces roches renferment des phénocristaux de hornblende qu'on ne trouve pas dans la formation de Masset.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

Mapping of the Masset Formation on eastern and central Graham Island (Hickson, 1988) was extended to the west coast during the 1988 field season (Fig. 1). This project, to resolve the internal structure and stratigraphy of the Masset Formation involves mapping, isotopic dating and petrology. It is hoped that some estimate of the duration, extent and type of volcanism, and the relative proportions of mafic to felsic magmas can be obtained.

The Masset Formation, named by Mackenzie (1916), was studied in detail by Sutherland Brown (1968). He recognized the wide variation in composition of the volcanic rocks

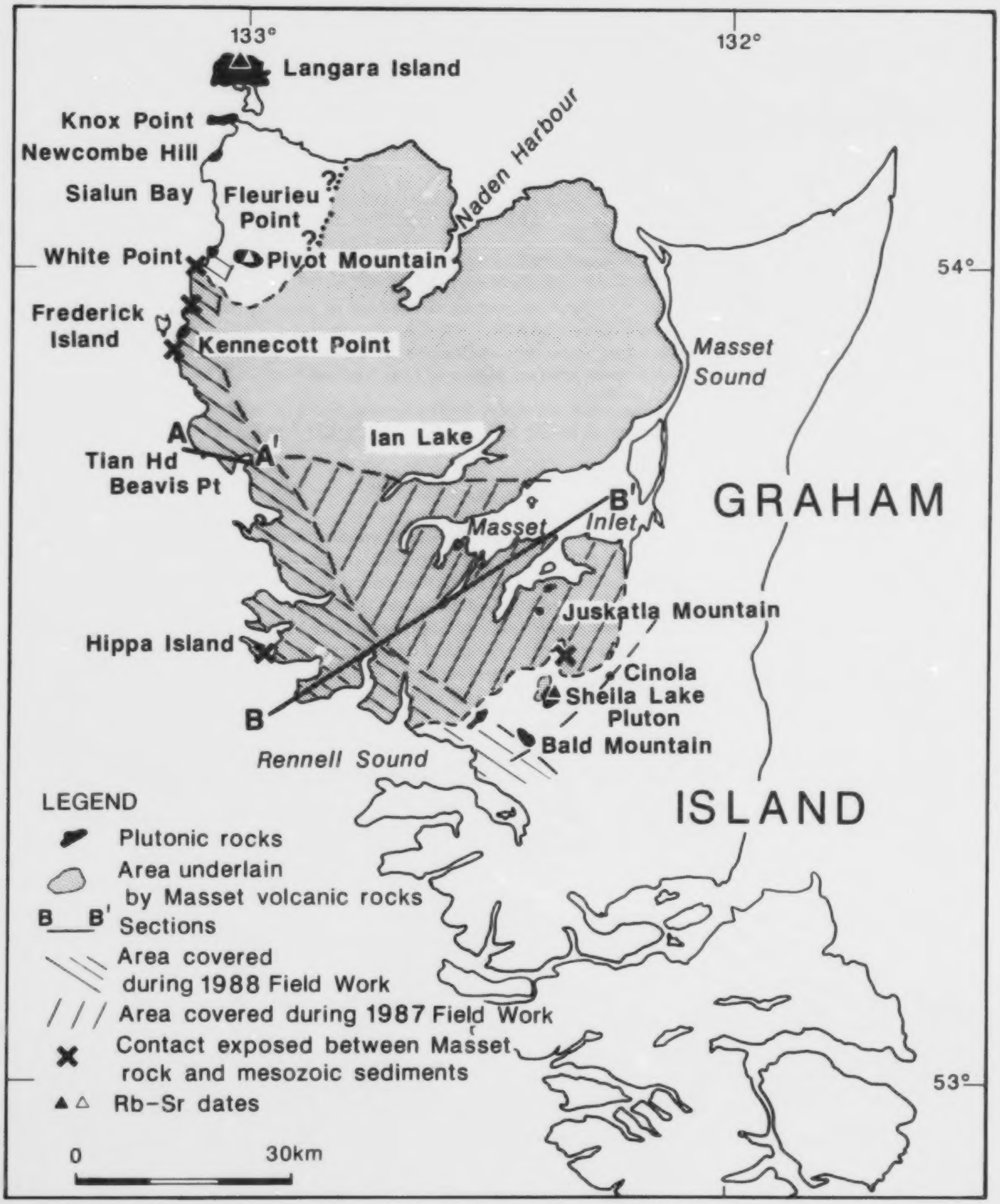

133°
132°
Langara Island
Knox Point
Newcombe Hill
Sialun Bay
Fleurieu Point
?
Naden Harbour
White Point
Pivot Mountain
54°
Frederick Island
Kennecott Point
Masset Sound
A
A'
Tian Hd
Ian Lake
Beavis Pt
B'
Masset
Inlet
GRAHAM
Juskatla Mountain
Hippa Island
Cinola
Sheila Lake
Pluton
B
Bald Mountain
Rennell Sound
ISLAND
LEGEND
Plutonic rocks
Area underlain by Masset volcanic rocks
B B' Sections
Area covered during 1988 Field Work
Area covered during 1987 Field Work
Contact exposed between Masset rock and mesozoic sediments
▲ △ Rb-Sr dates
53°
0
30km

Figure 1. Location map showing study area.

(from basalt to rhyolite) and proposed Paleocene to Miocene age for the succession. Young (1981) suggested a Late Cretaceous to Pliocene age for the Masset volcanism. Work by Hamilton (1985) and Cameron and Hamilton (1988) determined a more restricted, Early Eocene to Late Miocene, age for the volcanism. Hickson (1988), based on a compilation of K-Ar dates, pointed out that Masset volcanism occurs from Late Oligocene to Late Miocene with the bulk of the activity occurring in the Early Miocene (20-25 Ma). Palynological evidence, from samples collected during the 1987 field season, is not definitive but supports the more restricted age range (Table 1). During the 1988 field season, older volcanic rocks were found to be lithologically distinct from the Masset rocks studied and probably represent separate magmatic episodes (*see also* Haggart et al., 1989).

The Late Oligocene to Late Miocene Masset Formation on Graham Island consists of intercalated basalt to rhyolite flows and pyroclastics. Interflow sediments are minimal and there is little evidence of weathering between eruptive events. Felsic pyroclastic rocks predominate, although rhyolite flow units are locally abundant. Mafic rocks form multiple units in which individual flows range in thickness from 2-30 m and are associated with thin (a few tens of centimetres or less) interflow breccias. Diamictons in both the felsic and mafic sections have limited lateral extent and probably represent channelized debris flows.

Sutherland Brown (1968) described the Masset Formation as consisting of alkalic basalts and sodic rhyolites. According to petrochemical work by Hamilton (1985) and Dostal and Hamilton (1988), the rocks are described as ranging in composition from T-MORB to metaluminous rhyolite. Dostal and Hamilton (1988) suggested that most compositions reflect pronounced fractional crystallization and some degree of magma mixing.

The 1988 field season concentrated on a coastal strip extending from White Point to Rennell Sound (Fig. 1), and the region around Juskatla Mountain and Cinola was studied in greater detail. Mapping at 1:50 000 scale is based on foot traverses with vehicle, boat and helicopter support.

STRATIGRAPHY AND PETROLOGY OF THE MASSET FORMATION

The stratigraphy of central and eastern Graham Island (Hickson, 1988) generally applies to the western area. The principal difference between west coast exposures and those to the east is the prevalence of sedimentary units intercalated with the volcanic flows and pyroclastics. These sedimentary units range from coarse conglomerates to fine grained sand and siltstones and commonly contain silicified and carbonized wood debris. Several localities expose layers, up to 30 cm thick, of flattened logs within the volcanic-sedimentary sequence.

Mafic flows along the west coast may have lower silica values than those found to the east, indicated by cumulate (mantle-derived?) nodules found in some flows. Near Tian Head, plagioclase nodules (up to 8 cm) and megacrysts (up to 3 cm) were found. Pyroxene nodules (Fig. 2) and megacrysts occur in flows and breccias exposed along the coast between White and Kennecott points.

Table 1. Palynological report on Masset Formation samples

Sample	Lat.	Long.	Probable age
CH 87-61-01c	53°43′11″	132°36′38″	Eocene-Pliocene
CH 87-61-01a	53°43′11″	132°36′38″	L. Miocene-E. Pliocene
CH 87-23-11e	53°33′18″	132°22′29″	L. Miocene-E. Pliocene
CH 87-25-15c	53°33′20″	132°22′22″	Eocene-Pliocene
CH 87-27-11b	53°34′50″	132°23′37″	undeterminable
CH 87-28-09e	53°32′30″	132°26′44″	pre-Quaternary
CH 87-33-02a	53°35′02″	132°44′18″	undeterminable
CH 87-33-02b	53°35′02″	132°44′18″	pre-Quaternary
CH 87-02-18a	53°38′19″	132°21′31″	undeterminable
CH 87-02-18c	53°38′19″	132°21′31″	undeterminable

Identifications by J.M. White (pers. comm., 1988)

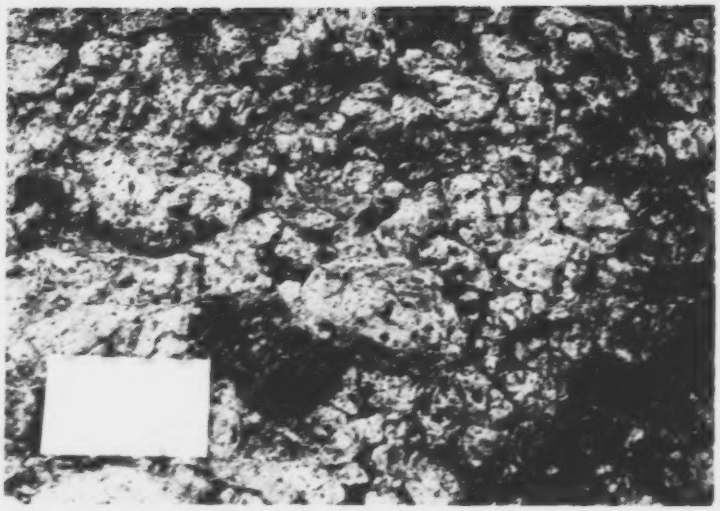
Except for these megacrysts and nodules, flows of the Masset Formation contain phenocrysts which are 3 mm or less in size and are limited in variety. Despite their calc-alkaline chemical signature (Fig. 3), the flows are not typical of calc-alkaline flows which generally contain varied, large (0.5-1 cm) phenocrysts. In the Masset Formation, feldspar is the only phenocryst phase that is consistently present; quartz, pyroxene and magnetite are rare. Pyroxene phenocrysts, found in a small percentage of rocks classified in the field as both felsic and mafic, are characteristic of rocks whose silica content straddles the andesite-dacite compositional boundary (Fig. 3).

For field mapping, the Masset Formation was divided into seven units based upon the phenocryst assemblage and estimates of the whole rock chemistry. Felsic rocks, all of which have an aphanitic groundmass, are subdivided into three units: 1) aphyric, 2) feldspar phyric, and 3) quartz-feldspar phyric. The mafic rocks are: 4) aphyric and aphanitic, and 5) aphanitic with plagioclase phenocrysts. Sedimentary units were subdivided into: 6) reworked primary volcanic rock, and 7) primary volcanic deposits emplaced by sedimentary processes.

The succession from Tian Head to Beavis Point perhaps best illustrates both the mixed mafic and felsic nature of the Masset Formation and the sedimentary units intercalated with the volcanic units (Fig. 4). The section includes nodule-bearing mafic flows, debris flows, felsic pyroclastics and flows, as well as coarse- to fine grained, well-bedded sandstones.

Layering along the west coast dips from 10-30° to the west but flattens eastward where thick rhyolite flows predominate. These flows (possibly domes) are up to 200 m thick and underlie a range of hills just inland of the coast. East of this line of hills, flows dip consistently east to northeast.

Figure 2. Pyroxene nodule in a block-lapilli breccia north of Kennecott point.



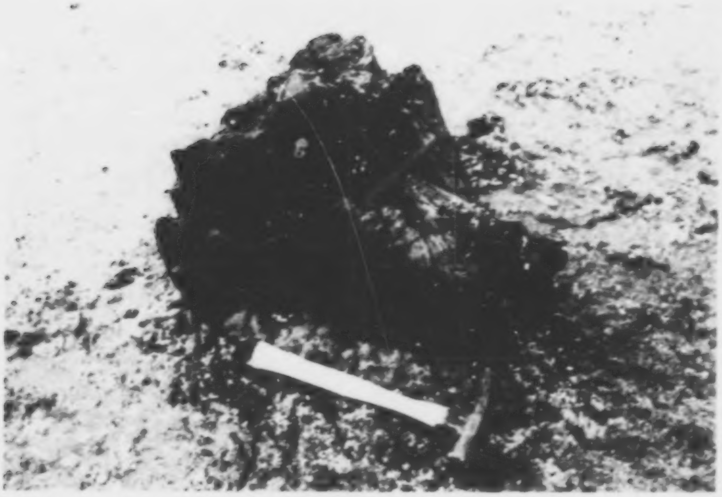


Figure 3. Tree stump protruding through eroded surface of pyroclastic airfall deposit at White Point.

The continuity of some units is better seen along the coast than inland. A felsic pyroclastic unit exposed along 1.5 km of wave-cut terrace at White Point can be traced for a farther 5 km along the beach south of Kennecott Point. Lithologically similar breccia material outcrops as a thick (150 m) flow at the base of the hills 3 km inland from the coast. This pyroclastic unit rests unconformably on conglomerates of the Longarm Formation (H.W. Tipper, pers. comm., 1988). At the base of the pyroclastic unit is a 1 m thick airfall layer composed of pumiceous clasts up to 2 cm across and lithic fragments reaching 1 cm. Carbonized and silicified tree stumps up to 1.5 m in diameter (Fig. 5) are present in the airfall deposit which has been scoured and overlain by a 30 m thick pyroclastic flow.

VOLCANIC ROCKS OLDER THAN THE MASSET FORMATION

Sutherland Brown (1968) indicated outcrops of Masset Formation north of White Point. These outcrops were examined in 1988. All are lithologically unlike Masset rocks seen to the south. At Fleurieu Point and Sialun Bay dykes and sills contain hornblende phenocrysts, whereas Newcombe Hill is a high level plutonic body. Subaerial flows seen in this region may also be older than the Masset Formation because on Lucy Island (between Langara and Graham islands) a feldspar-biotite-phyric flow is overlain by finely laminated siltstone of the Honna Formation. This volcanic rock lithologically resembles that at Cape Knox where a 45.7 ± 3 Ma K-Ar date (Young, 1981; recalculated with new constant)

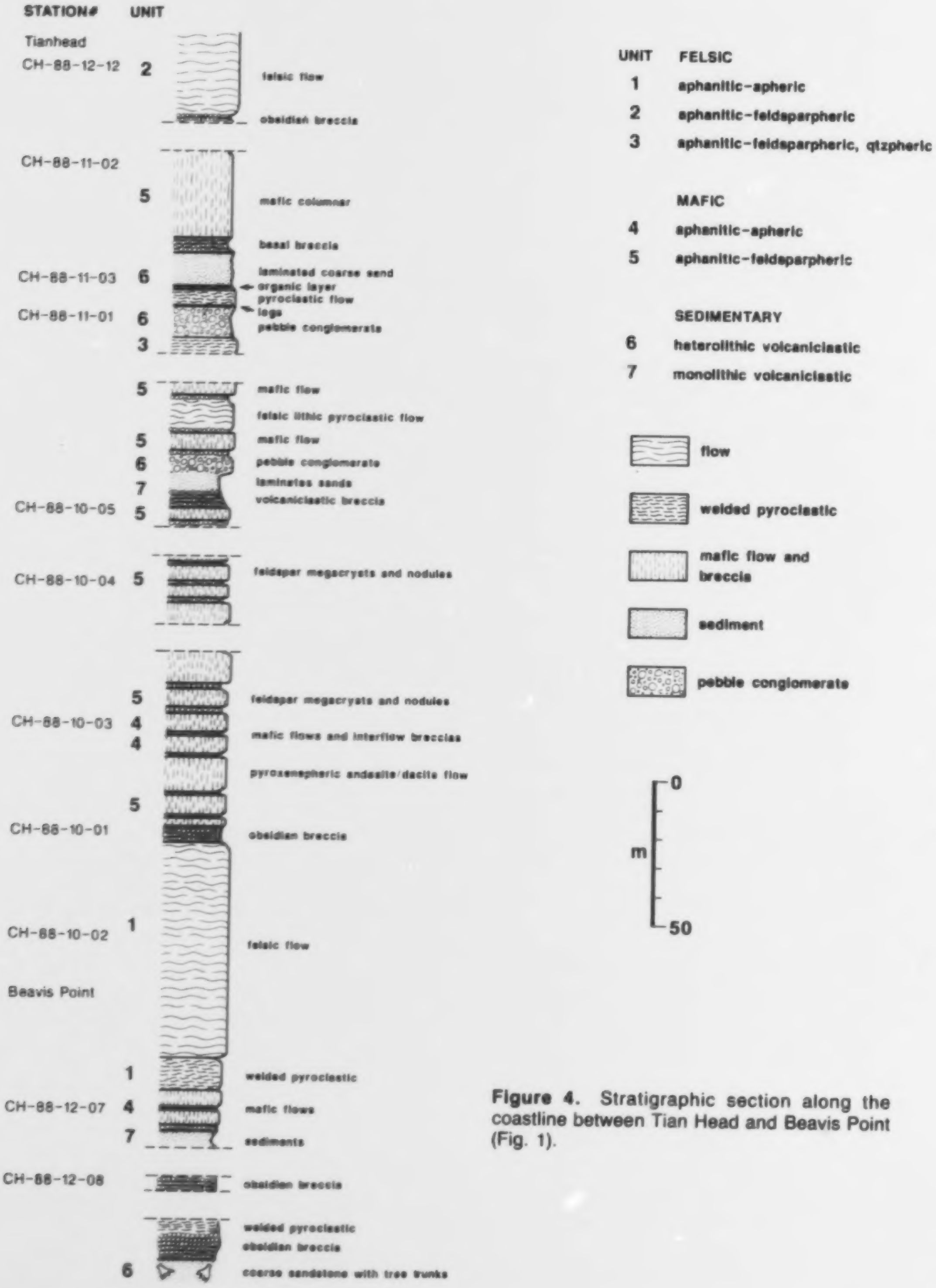

STATION#
UNIT
Tianhead
CH-88-12-12
2
felsic flow
obsidian breccia
CH-88-11-02
5
mafic columnar
basal breccia
CH-88-11-03
6
laminated coarse sand
organic layer
pyroclastic flow
CH-88-11-01
6
logs
pebble conglomerate
3
5
mafic flow
felsic lithic pyroclastic flow
5
mafic flow
6
pebble conglomerate
7
laminates sands
volcaniclastic breccia
CH-88-10-05
5
CH-88-10-04
5
feldspar megacrysts and nodules
5
feldspar megacrysts and nodules
CH-88-10-03
4
mafic flows and interflow breccias
4
pyroxenepheric andesite/dacite flow
5
CH-88-10-01
obsidian breccia
CH-88-10-02
1
felsic flow
Beavis Point
1
welded pyroclastic
CH-88-12-07
4
mafic flows
7
sediments
CH-88-12-08
obsidian breccia
welded pyroclastic
obsidian breccia
6
coarse sandstone with tree trunks
UNIT
FELSIC
1 aphanitic-apheric
2 aphanitic-feldsparpheric
3 aphanitic-feldsparpheric, qtzpheric
MAFIC
4 aphanitic-apheric
5 aphanitic-feldsparpheric
SEDIMENTARY
6 heterolithic volcaniclastic
7 monolithic volcaniclastic
flow
welded pyroclastic
mafic flow and breccia
sediment
pebble conglomerate
0
m
50

Figure 4. Stratigraphic section along the coastline between Tian Head and Beavis Point (Fig. 1).

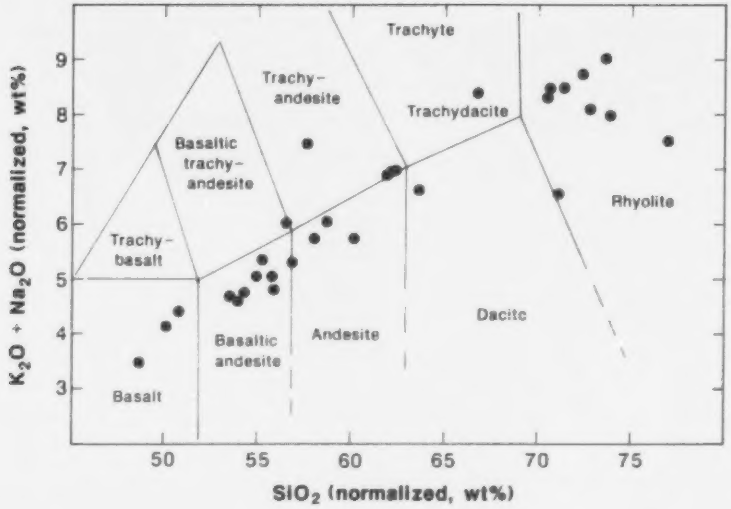


Figure 5. Total alkali versus silica for the Masset Formation. Fields are from LeBas et al. (1986).

was obtained from a rhyolite ash flow tuff. On Langara Island feldspar-phyric mafic and felsic flows are interbedded with the Haida Formation. Anderson and Greig (1989) noted that these volcanics are cut by the Langara Island pluton which gave a U-Pb date of 27 Ma (Anderson and Reichenbach, 1989).

Farther south, in the vicinity of Rennell Sound, volcanics previously mapped as Masset (Sutherland Brown, 1968) were found to be hornblende-biotite-quartz phyric-rocks which are not in stratigraphic continuity with Masset rocks, suggesting they may represent an older phase of volcanism. Nearby, a biotite-feldspar porphyritic intrusive body (64 ± 3 Ma K-Ar date; Mathews, 1964; recalculated with new constants) was obtained from rocks on Bald Mountain. Immediately north is a southeasterly-trending ridge capped by a pebble-cobble conglomerate unit lithologically related to the Upper Cretaceous Honna Formation. This conglomerate contains plutonic clasts resembling the Bald Mountain intrusion and volcanic clasts resembling the rocks seen closer to Rennell Sound. In the vicinity of Long Inlet mafic (probably andesitic) flows interfinger with conglomerates of the Honna Formation and are described by Haggart et al., (1989).

In the area near Cinola, distinctive quartz-eye porphyry dykes cut rocks of the Yakoun and Haida formations. Detailed mapping has revealed a quartz-phyric flow within fine grained shales of the shale member of the Haida Formation (J. Deighton, pers. comm., 1988). Isolated exposures of hornblende-phyric rocks were found in an area mapped as Yakoun Formation by Sutherland Brown (1968), south of the proposed mine site (M.A. Hepp, pers. comm., 1988).

STRUCTURE IN THE MASSET FORMATION

The anticline shown by Sutherland Brown (1968) parallel to the west coast of the island is here interpreted as a constructional feature. Stratigraphic thickness and facies transitions indicates that a topographic high paralleled the present-day coastline slightly inland. This high could have been the vent area which shed eruptive products and sediments to the east and west (Fig. 6), thus eastward tilting is not necessary to explain dip directions. Wave-cut terraces suggested to be the result of uplift along the west coast (Sutherland Brown, 1968) are not unique to that locale and cannot be used as evidence of tilting.

Near Juskatla Mountain, steep north trending normal faults with an east-side-down sense of motion are exposed and inferred from outcrop pattern and orientation. Three closely spaced en echelon faults indicate cumulate displacement of 10 m. Some units have been tilted to vertical, further suggesting a steep fault(s). Masset Sound, parallel to this trend, probably contains a major fault because Masset volcanic rocks are exposed only on the west side and are not present at the surface on the east.

A postglacial landslide deposit, 2 km long, on the northwest side of Juskatla Mountain parallels the trace of a steep north trending fault. The headwall is at 490 m and debris was carried to the base of Towustasin Hill at 200 m elevation.

On Graham Island, intrusions appear to be spatially associated with extrusive Masset rocks. The plutons give U-Pb dates of 26-28 Ma (Anderson and Reichenbach, 1989) contemporaneous with early phases of Masset volcanism. Both the northern and southern boundaries of the Masset Formation follow trends which roughly parallel the trend of major topographic features (Naden Harbour, Ian Lake, and Juskatla Inlet) and dykes near Rennell Sound (Souther, 1988). At present, it is not known whether (or how) the relationships relate to the structural history of Graham Island.

DISCUSSION

The regional dip of the volcanic units reflects primary slopes rather than significant eastward tilting. Preliminary paleomagnetic results (Wynne and Hamilton, 1989) however, suggest tilting but indicate no consistent orientation.

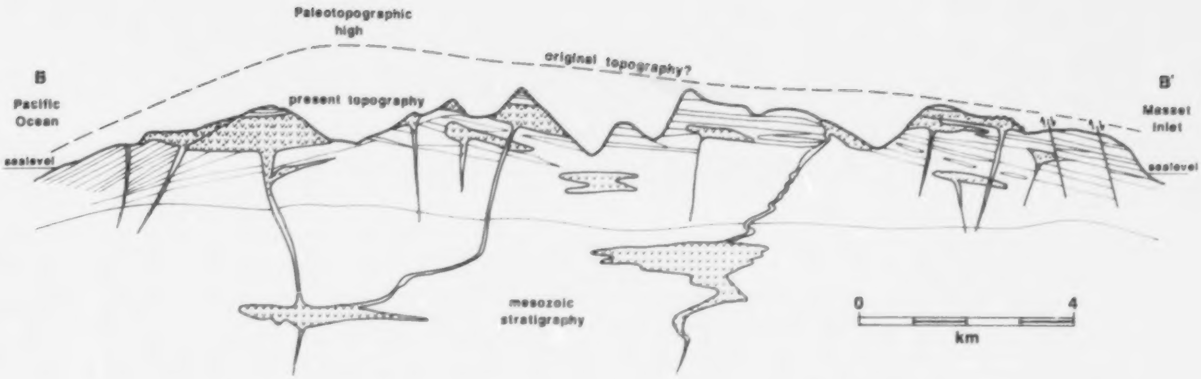


Figure 6. Hypothetical section along B-B' (Fig. 1) from the west coast of Graham Island to east of Masset Inlet. Two-times vertical exaggeration.

Volcanic rocks have not previously been noted in outcrops of the Albian and younger Cretaceous Queen Charlotte Group, although volcanics have been intersected in drillholes (Young, 1981). Previously, volcanic rocks were assigned to either the Masset Formation, Yakoun Group or Karmutsen Formation, but the occurrences near Langara Island, Cinola and Long Inlet cannot be correlated with any of the above units. Volcanic rocks with ages in the time span that is post-Yakoun Group and pre-Masset Formation (as used in this paper) should be considered separately, either as distinct formations or as members within existing formations.

ACKNOWLEDGMENTS

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Polarity and inclination of magnetization of the Masset Formation from a deep drillhole on Graham Island, Queen Charlotte Islands, British Columbia

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Wynne, P.J., and Hamilton, T.S., Polarity and inclination of magnetization of the Masset Formation from a deep drillhole on Graham Island, Queen Charlotte Islands, British Columbia; in *Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 81-86, 1989.*

Abstract

A 1147.9 m cored section of the Masset Formation contains two distinctive lithological successions and (from top to bottom) reversed, mixed and normal polarity packages. The magnetostratigraphy of this borehole could serve as a powerful correlation tool for exploration drilling in the Masset Formation beneath northern Graham Island and Dixon Entrance. The mean inclination of the undeformed part of the core is 69 ± 3° (standard error) which is not significantly different from the inclination of the cratonic reference paleopole for the Early Miocene. Therefore, there has been no appreciable north-south movement of the Queen Charlotte Islands relative to North America since the deposition of the Masset Formation.

Résumé

Une section de carotte de 1147,9 m de la formation de Masset renferme deux successions lithologiques distinctes et (de haut en bas) des ensembles de polarité inversée, mixte et normale. La magnétostratigraphie de ce sondage pourrait servir d'outil important pour la corrélation de forages d'exploration dans la formation de Masset, située en-dessous de la partie nord de l'île Graham et de l'entrée Dixon. L'inclinaison moyenne de la partie non déformée de la carotte est de 69° ± 3° (erreur-type), ce qui diffère très peu de l'inclinaison du paléopôle de référence cratonique pour le Miocène inférieur. Par conséquent, il n'y a pas eu de mouvement nord sud notable des îles de la Reine-Charlotte par rapport à l'Amérique du Nord depuis la mise en place de la formation de Masset.

INTRODUCTION

In 1984 Bow Valley Industries diamond drilled a borehole (BVI Naden b-A27-J/103-F-15) in the first meander bend of Davidson Creek upstream from Naden Harbour, on the north end of Graham Island (53.94°N, 132.70°E, Fig. 1). Their objective was to drill through the Tertiary Masset Formation into the underlying Cretaceous Queen Charlotte Group. The hole was collared in unconsolidated overburden and continuously cored from 25.6 m to its bottom at 1147.9 m, in volcanics of the Masset Formation.

In this paper we describe the sequence of magnetic reversals in the core, and assess their potential as a correlation tool within the Masset Formation, and we compare the mean inclination of the core to that of the cratonic reference field.

The core was described and subsampled on site in November 1984 at the close of drilling by one of us (TSH). Representative samples of the freshest material were collected from each of the more than 200 lava flows, pyroclastic units, sedimentary interbeds and paleosol horizons which comprise the Masset Formation (Fig. 2a). The stratigraphic description and rock types are from Hamilton (in prep.) and Dostal and Hamilton (1988). Subsamples for paleomagnetism came from dense flow interiors and were marked with an arrow in the up direction. The physical units and lithological breaks were accurately described by the wellsite geologist J. Paterson (1984), but the interpretation of individual flows or eruptive units is inconsistent and the rock nomenclature and descriptions of physical volcanology is not according to standard volcanological practice.

STRATIGRAPHIC SUMMARY

Tertiary magmatic activity assigned to the Masset Formation spans 41 to 11 Ma in three pulses, with diachronous stratigraphy that youngs to the north (Cameron and Hamilton, 1988). The stratigraphy of the BVI Naden hole is from the youngest (Early Miocene) pulse of volcanism, because samples from 61.9 m and 1123.0 m (Fig. 2a) yielded whole rock K-Ar ages of 23.0 and 23.6 ± 0.8 Ma respectively.

The Masset Formation in the hole comprises volcanic flows and pyroclastics with minor intervals of thin interflow epiclastic sediments and rare tuff beds. There are two lithologic packages. The upper, above 646 m, is dominated by basalt flows. The lower is a mixture of andesitic to dacitic flows, agglomerates and epiclastic sediments. Dacites become more abundant towards the bottom of the hole (Fig. 2a).

Above 646 m, the core is almost entirely basaltic with a repetitive succession of thin aphyric flows. The flows have variably developed oxidized flow-base agglomerates, oxidized flow-tops and rare, thin, interflow clay layers. At least six faults (indicated by slickensides, gouge or breccia, change of lithology, and missing flow tops or bases) were noted between the surface and 367.3 m (Fig. 2a). The inclined flow textures and geopetal structures (amygdules, pipe vesicles, vugs, veins) in this faulted part of the succession indicate that flows are tilted by up to 30°. Dips of slickensides and fault gouge range from subvertical to 40°; with lineations indicating both strike-slip and dip-slip motion. Below 367.3 m flow contacts, bedding planes and geopetal structures show that the beds are essentially horizontal.

Below 421.5 m but within the upper basaltic unit of the core, seven thin sedimentary horizons (including a few paleosols) mark local unconformities and hiatuses in volcanism. Flows in this part of the section generally have reddish, oxidized tops and bases, indicating hot, auto-oxidation during extrusion. Clay layers and thin epiclastic sands are greenish. A thin, graded bed of basaltic gravel to sand near 486.0 m indicates subaqueous deposition. A pastel ash horizon near 609.6 m suggests that the upper section, although dominated by basalt, is distal to more explosive, felsic volcanism. The base of the upper basaltic part of the core near 646.0 m is marked by a permeable unconformity; pronounced water flow was reported at this depth during drilling.

Below 643 m, the core is highly variable in composition. It is dominated by thick, porphyritic andesite flows from which most of the paleomagnetic samples were obtained. Subordinate felsic and mafic flows and epiclastic sediments (conglomerate, tuffaceous sand, lahar) are present in roughly equal amounts. The thickest sedimentary interbeds are between 703.0 and 831.0 m; these mark hiatuses in volcanism. Two basalt flows near 884.0 and 1028.7 m indicate

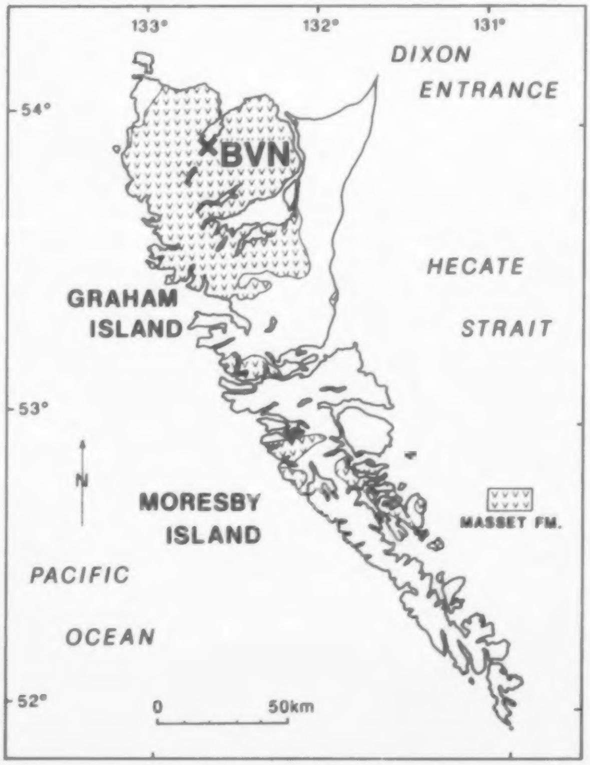

Figure 1. General distribution of Masset Formation and location of the Bow Valley Naden Harbour borehole (BVN), Queen Charlotte Islands.

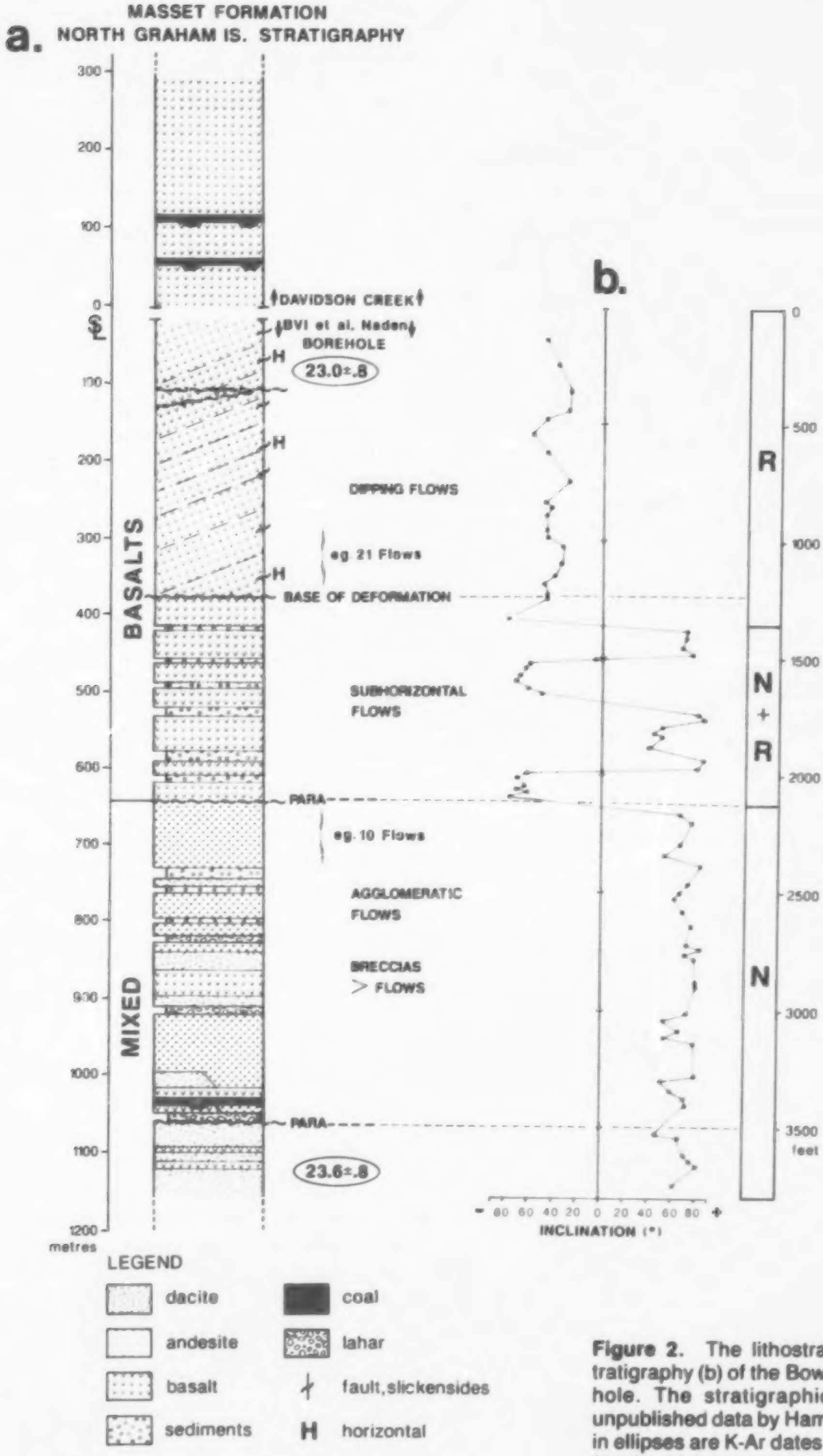

Figure 2. The lithostratigraphy (a) and magnetostratigraphy (b) of the Bow Valley Naden Harbour borehole. The stratigraphic section (a) is based on unpublished data by Hamilton. The numbers enclosed in ellipses are K-Ar dates Ma. PARA denotes paraconformity. H denotes a horizontal slickensides. The total number of flows and beds in the cored interval is 205; most compositional blocks represent multiple flows as indicated by parentheses. in the inclination log (b), N are normal (positive) inclinations (to the right) and R reversed (negative) inclinations (to the left).

great compositional variation and the potential for pronounced facies changes in rocks that may be lateral equivalents to this lower unit. The polymictic nature of the lahars and the occurrence of weathered flow tops suggest sporadic and discontinuous volcanism. Below 1063.7 m, pink and grey dacite flows are dominant. Many of these lower flows are incompetent, fractured, and too altered for paleomagnetic analysis.

PALEOMAGNETIC METHODS

In the laboratory, cores 2.2 cm in diameter were drilled parallel to the long axis of the larger diameter, primary cores. The up direction was transferred to the subsampled cores. These were cut into two or more specimens, 2.2 cm long. The direction (declination and inclination) of magnetization of specimens from one individual core can be compared whereas only the inclination of specimens from different subsamples is comparable.

The natural remanent magnetization (NRM) of each specimen was measured. Five pilot specimens, at intervals of from 106-198 m down the drill hole, were demagnetized incrementally using an alternating magnetic field (AF). All five samples have single-component magnetizations (Fig. 3) exhibiting linear decay to the origin in fields from 10-100 mT. The remaining specimens were demagnetized at 40 mT with most retaining about 50% of their NRM intensity. The NRM and 40 mT results are listed in the Appendix.

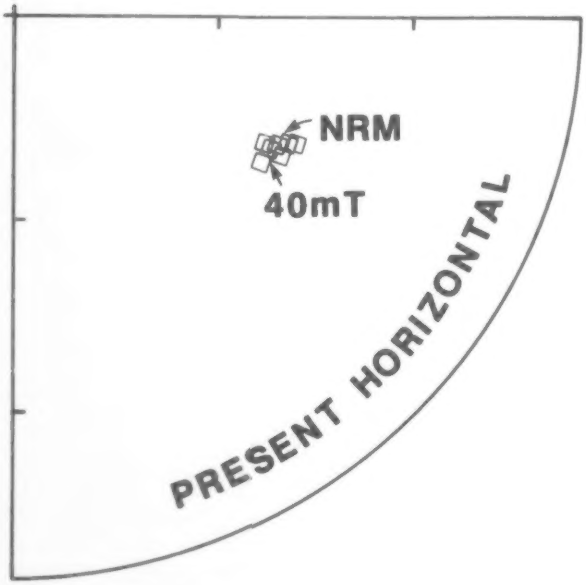

Figure 3. Detailed AF demagnetization of specimen from 358.7 m. Squares denote downward (reversed) directions in the southeast quadrant of a Schmidt stereographic projection.

POLARITY

The polarity changes five times over the depth of the core (Fig. 2b). The core down to 413.0 m has negative inclination (reversed polarity), and the core below 647.1 m shows positive inclination (normal polarity). These two intervals comprise 75% of the hole. Between the reversed upper part and the normal lower part the polarities are mixed, with two normal and two reversed horizons.

The earth's field has changed polarity (from normal to reverse or reverse to normal) 34 times over the 10 Ma time span of the Early Miocene (Harland et al., 1982). The five polarity swings in the middle part of the core may thus represent about 1.5 Ma of time. This estimate falls within the error bounds of the K-Ar whole-rock ages (23.0 and 23.6 ± 0.8 Ma).

It is not possible to uniquely correlate individual polarity changes with the global time scale. However, the polarity sequence reversed/mixed/normal may provide a useful regional correlation tool when used in conjunction with lithostratigraphy.

MEAN INCLINATIONS

The arithmetic mean inclinations from the core are summarized in Table 1. The mean inclinations referred to in the following discussion and illustrated in Figure 2b are those of the cleaned (40 mT) directions and the errors are standard errors. The expected inclination for Early Miocene rocks deposited at this location is 70 ± 1° (calculated using the 20 Ma cratonic reference paleopole of 88°N, 121°E, $\alpha63=2$; Irving and Irving, 1982). In a reconnaissance study of surface samples from the Masset Formation, Hicken and Irving (1977) reported a mean inclination of 78°, $\alpha95=6$, $\alpha63=4$.

The mean inclination of all the data, irrespective of sign, is shallow (61 ± 2°, Table 1). This may reflect incomplete cleaning. However, the linearity of the orthogonal decay plots indicates single-component magnetization and argue against the presence of any normal overprint.

The upper, deformed part of the hole, corresponding roughly to the first reversed interval (Fig. 2b), has very shallow inclinations (-46 ± 3°). As discussed above, this interval contains paleohorizontal indicators inclined up to 30° and is cut by many faults.

The mean paleomagnetic inclination (irrespective of sign) of the undeformed portion of the hole (below the base of the upper reversed interval at 413.0 m) is 67 ± 1°. A mean inclination of 69 ± 3° is obtained by converting inclinations to colatitudes prior to averaging (Cox and Gordon, 1984). The mean thus obtained is not significantly different from the expected cratonic inclination of 70 ± 1° but is shallower than the 78 ± 3° observed by Hicken and Irving (1977). At the time of their study the age of the Masset Formation was thought to be Paleocene and they concluded that the Queen Charlotte Islands had undergone a clockwise

Table 1. Mean Inclinations

By polarity interval, from the top:

	(NRM)			(40 mT)			
Interval	N	I	sd	N	I	sd	se
Reversed	18	−42	13	20	−46	12	3
Normal	5	71	3	4	70	3	1
Reversed	6	−51	10	6	−65	7	3
Normal	8	67	17	8	63	20	7
Reversed	5	−67	9	6	−69	6	3
Normal	32	71	9	32	68	10	2

For the entire hole:

	(NRM)			(40 MT)			
Interval	N	I	sd	N	I	sd	se
N&R	76	60	18	77	61	16	2
Reversed	29	−48	15	33	−53	16	3
Normal	47	68	16	43	67	12	2
>1355′ N&R	56	68	12	56	67	11	1
>1355′ N&R					69		3
Expected					70		1*
Hicken and Irving					78		3*

N is the number of specimens or specimen pairs; I is the arithmetic mean inclination in degrees below the horizontal; sd is the standard deviation of the mean; se is the standard error of the mean $(sd/\sqrt{N})$; * marks $\propto 63$ errors (the radius of the circle of confidence around the mean direction, P=.37). sd, se, and $\propto 63$ are given in degrees. C&G inclination was calculated using an analysis of inclination only, as described by Cox and Gordon (1984). The expected inclination was calculated using the 20 Ma paleopole for cratonic North America (Irving and Irving, 1982). The last line gives the mean inclination of the Masset Formation from the reconnaissance study of Hicken and Irving (1977).

rotation of 25°. Their results, when compared with the cratonic Neogene paleopole show no significant rotation but, because of the steepness of the inclination, do show a paleolatitude offset of 14° to the south. Hicken and Irving's steep mean inclination was not duplicated in this study, presumably due to more complete averaging obtained from this long borehole section.

SUMMARY

The five changes in polarity suggest that roughly 1.5 Ma of the Masset depositional history is represented by this hole. This estimate is generally consistent with the available K-Ar dates. The three polarity packages (reversed, mixed and normal) may constitute a useful regional correlation tool for Masset Formation stratigraphy on northern Graham Island and beneath Dixon Entrance. The sequence of polarity changes is discernable even without AF cleaning, thus future magnetostratigraphic studies of this interval could use raw NRM values.

The mean inclination of the core (69 ± 3°) below 413.0 m is not significantly different from the expected inclination (70 ± 1°) for the Queen Charlottes in the Miocene. Therefore, since the deposition of the Masset Formation, the Queen Charlotte Islands have not moved appreciably relative to the craton.

ACKNOWLEDGMENTS

We thank Cathy Hickson for her assistance in removing paleomagnetic specimens from the core subsamples and for her enthusiasm regarding this project. Thanks are also owing to Ted Irving for his thoughtful guidance throughout the study.

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APPENDIX

Paleomagnetic inclinations from appendix volcanics of the Bow Valley Naden Harbour well

Sample	NRM			40 mT	
Number	I	M	θ63	I	θ63
141.0	-46.	.585E-2	1	-48	1
246.0	-30.	.599E-3	1	-40	1
361.0	-25	.518E-3	1	-30	1
441.0	-27	.976E-3	3	-32	4
471.0	-45	.185E-2	4	-48	2
539.0	-60	.653E-2	1	-62	1
623.5	16	.426E-3	9	-49	3
746.0	9	.854E-3	6	-30	2
830.0		.415E-3		-51	6
854.0	-43	.226E-2	1	-46	2
896.0	-38	.354E-3	7	-49	1
929.0	-41	.511E-2	1		
953.0	-46	.557E-2	4	-49	3
979.0	-43	.883E-2	1	-49	8
1020.5	-31	.286E-3	6	-36	3
1095.5	-36	.139E-2	2	-38	3
1142.5	-30	.906E-3	5	-44	1
1177.0	-45	.422E-2	3	-49	8
1217.5	-42	.565E-3	—	-48	—
1242.0	-42	.712E-3	—	-47	—
1334.0	-83	.398E-3	4	-84	4
1383.0	68	.807E-3	2	69	2
1409.0	69	.108E-2	2	69	4
1448.0	72	.104E-4	2	66	4
1477.0	72	.999E-3	8	74	5
1500.0	76	.230E-5	1	-8	—
1519.0	-54	.637E-3	5	-63	6
1542.0	-68	.148E-2	—	-65	—
1573.0	-56	.208E-3	1	-71	2
1582.0	-42	.458E-3	5		
1600.0	-48	.541E-4	—	-74	—
1632.0		.303E-3		-63	4
1651.0	-43	.317E-3	8	-54	7
1743.0	80	.116E-2	—	78	—
1765.0	84	.833E-3	3	85	3
1796.0	70	.822E-3	1	49	6
1811.0	51	.588E-3	4	42	5
1827.0	48	.829E-3	—	48	—
1882.0	41	.638E-3	2	39	3
1935.0	82	.116E-2	2	84	6
1976.0	76	.195E-2	—	79	—
1995.0	-55	.123E-2	—	-63	5
2005.0	-65	.180E-2	3	-72	7
2048.0		.652E-2		-66	3
2057.0	-75	.152E-2	7	-73	4
2070.0	-65	.168E-3	—	-63	—
2087.0	-77	.340E-3	3	78	3
2166.0	82	.355E-2	1	62	4
2201.0	78	.488E-2	1	75	2
2295.0	72	.437E-2	—	66	—
2340.0	59	.428E-2	3	52	6
2386.0	79	.294E-2	1	83	2
2458.0	79	.614E-2	1	72	2
2505.0	67	.418E-2	1	65	6
2526.0	60	.480E-2	1	61	5
2595.0	76	.372E-2	2	67	7
2645.0	84	.218E-2	3	76	1
2724.0	76	.208E-2	—	71	—
2740.0	83	.306E-3	0	84	7
2754.0	77	.180E-2	3	68	4
2786.0	79	.221E-2	1	78	4
2881.0	73	.645E-3	—	78	—
2895.0	77	.103E-2	2	78	3
3011.0	76	.653E-2	—	74	—
3041.0	59	.393E-2	—	53	—
3086.0	68	.765E-3	6	66	4
3110.0	58	.532E-1	2	54	2
3144.0	73	.468E-2	—	69	—
3284.0	78	.880E-2	3	79	2
3298.0	59	.160E-2	—	51	—
3345.0	64	.121E-2	—	59	—
3377.0	73	.433E-2	—	70	—
3404.0	61	.263E-2	—	72	—
3422.0	53	.743E-2	8		
3528.0	53	.277E-2	—	45	—
3544.0	67	.472E-2	—	63	—
3613.0	84	.103E-2	—	70	—
3640.0	74	.142E-2	—	75	—
3666.0	79	.187E-2	—	81	—
3747.0		.907E-3		61	2

Sample numbers correspond to depths in feet below the Kelly Bushing (KB) as indicated on the core boxes. The KB elevation was 17.7 m above sea level. Results from companion specimens (cut from the same standard-sized cores) were averaged together as were the inclinations from multiple pairs from a single flow; only the mean inclination (*I*) and magnetization (*M*) is reported. (I) denotes the arithmetic mean inclination in degrees below the horizontal. M is the mean magnetization in amperes/m. θ63 is the angular radius in degrees of a circle about the mean containing 63% of the observations. Companion specimens where the θ63 of the mean direction was greater than 10 (6 of the NRM specimen pairs, and 3 of the 40 mT specimen pairs) have not been included in this analysis and are shown as blanks. Where only one specimen was taken from a flow, θ63 is shown as -. Specimen pairs which give a polarity different from core immediately above or below have been discarded, because there was no independent means of verifying the reliability of these single-flow indicators of excursions or reversals. Of the 91 specimen pairs measured these comprised 11 pairs or 12% of the paleomagnetic subsample.

Sedimentological aspects of the Skonun Formation, Queen Charlotte Islands, British Columbia[1]

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Higgs, R., Sedimentological aspects of the Skonun Formation, Queen Charlotte Islands, British Columbia; in *Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 87-94, 1989.*

Abstract

Oil-company boreholes in the Queen Charlotte Basin reveal a Miocene-Pliocene succession (Skonun Formation) up to 5 km thick, containing abundant sand bodies with reservoir potential. However, the depositional environment of the Skonun Formation, hence the geometry of the sand bodies, is poorly understood, partly because exposures and core are minimal.

Three exposures are described. The facies include coal beds and rooted mudstones; these are interpreted as delta-plain deposits, suggesting that some of the subsurface sand bodies could be distributary channels and delta-front sands. Similarly, tidal-shelf sandstones are present at outcrop, suggesting that linear tidal sand ridges could occur at depth.

Iceberg dropstones occur in probable Upper Miocene strata at one locality, despite faunal evidence that the climate was temperate. This is thought to indicate that the northern Coast Mountains of British Columbia were sufficiently high in Late Miocene time to produce glaciers capable of reaching the sea.

Résumé

Des trous de sonde, effectués par des sociétés pétrolières dans le bassin de la Reine-Charlotte, révèlent la présence d'une succession (formation de Skonun) du Miocène-Pliocène, atteignant une épaisseur de 5 km, qui renferme d'abondantes masses sableuses à potentiel de réservoir. Toutefois, on comprend mal le milieu de sédimentation de la formation de Skonun et donc la géométrie des masses sableuses, en partie à cause de la faible abondance des affleurements et des carottes.

Trois affleurements sont décrits. Les faciès renferment des couches de charbon et des pélites enracinées; ces dernières seraient constituées de sédiments de plaine deltaïque, phénomène qui laisse supposer que certaines masses sableuses de subsurface pourraient être des sables de bras de delta et de front de delta. De façon similaire, les grès de la partie tidale de la plate-forme continentale sont présents dans les affleurements et leur présence semble indiquer que des crêtes sableuses de plage, linéaires, pourraient se rencontrer en profondeur.

En un endroit, on trouve des blocs glaciaires déposés par des icebergs dans des couches qui datent probablement du Micoène supérieur, malgré que l'étude de la faune indique qu'un climat tempéré prévalait; on estime que cela indiquerait que la partie nord de la chaîne côtière de la Colombie-Britannique était suffisamment haute au Miocène supérieur pour produire des glaciers capables d'atteindre la mer.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

The Skonun Formation consists of marine and nonmarine sandstone, mudstone, conglomerate and coal of Tertiary age (Sutherland Brown, 1968). These sediments crop out in northeastern Graham Island, Hecate Strait and Queen Charlotte Sound (Fig. 1), beneath a veneer of Quaternary deposits. The Skonun Formation is generally thought to overlie the volcanic Masset Formation (e.g. Sutherland Brown, 1968); in detail, however, the upper Masset and lower Skonun probably interdigitate (Cameron and Hamilton, 1988).

Access to the Skonun Formation is limited to a few small exposures, some drill core at the Cinola gold property (Champigny and Sinclair, 1982), and fourteen oil-exploration boreholes drilled onshore and offshore in the 1950s and 1960s (Fig. 1). None of the boreholes encountered hydrocarbon accumulations. Core- and outcrop sections are seldom longer than 15 m, hampering environmental interpretation.

The Skonun Formation occupies a sedimentary basin up to 5 km deep known as the Queen Charlotte Basin (Fig. 1; Shouldice, 1971). The boreholes reveal an alternation of sand- and shale-dominated intervals ranging from tens to hundreds of metres thick (Shouldice, 1971). Wireline logs cannot be correlated from one hole to another (Shouldice, 1971).

The Skonun Formation includes Miocene and Pliocene strata, based on foraminifera, palynomorphs and molluscs (Sutherland Brown, 1968; Shouldice, 1971; Addicott, 1978; Champigny et al., 1981). However, much of the succession is nonmarine and poorly dated, and could include pre-Miocene sediments.

The Skonun Formation will be of great importance in any future hydrocarbon exploration program in the Queen Charlotte Islands region because it includes abundant sandstone with high porosity (Shouldice, 1971), and because it has the highest mineralogical maturity of all the formations exposed on the islands (Sutherland Brown, 1968). However, little is known about the depositional environment of the Skonun Formation. A thorough understanding of depositional environment is essential for predicting the subsurface distribution and geometry of (potential reservoir) sandstone bodies.

Any depositional model for the Skonun Formation will necessary lack refinement because of the shortage of exposure and core. Hence it is important to extract the maximum amount of information from the available exposures. Figure 1 shows all of the Skonun Formation exposures

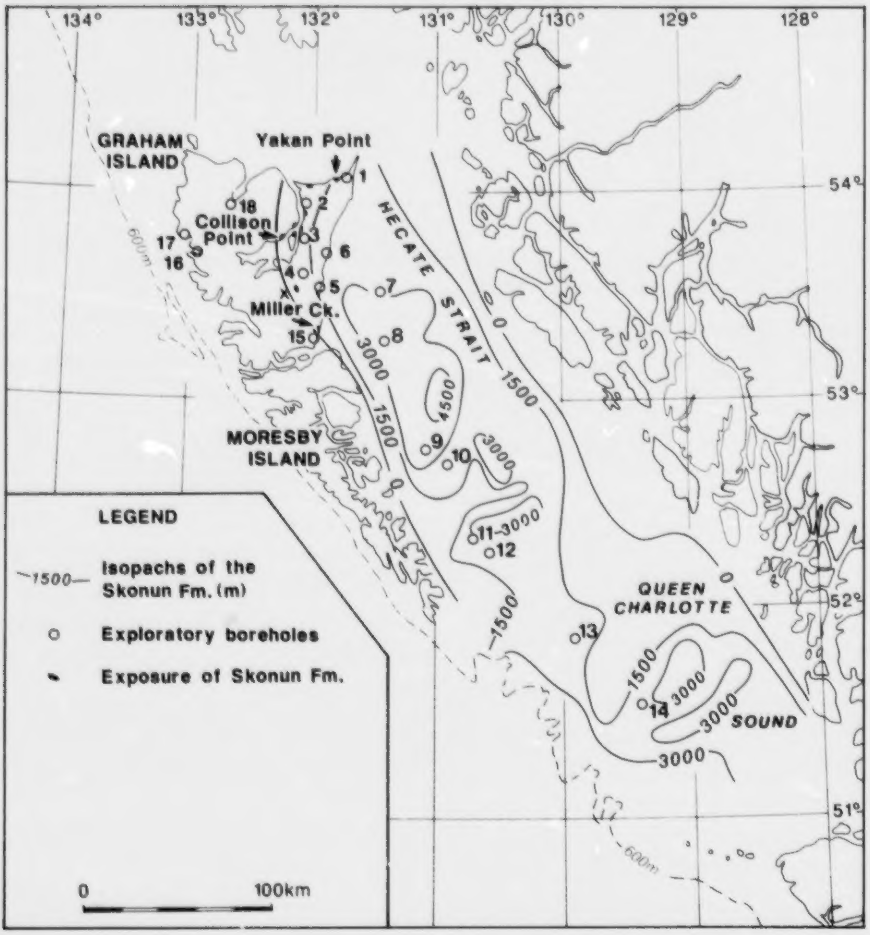

Figure 1. Location map of the Queen Charlotte Islands region, showing Skonun Formation isopachs and exposure. Isopachs, from Shouldice (1973), are based on borehole and geophysical data. The three exposures visited in the present study are shown by arrows. Exploratory boreholes: 1 Tow Hill; 2 Masset; 3 Nadu River; 4 Gold Creek; 5 Tlell; 6 Cape Ball; 7 South Coho; 8 Tyee; 9 Sockeye B-10; 10 Sockeye E-66; 11 Murrelet; 12 Auklet; 13 Harlequin; 14 Osprey; 15 Queen Charlotte; 16 Port Louis; 17 Tian Bay; 18 Naden. Cinola gold property is marked by an "x".

mapped by Sutherland Brown (1968). Three of these exposures were visited by the author during the summer of 1988 and are described below.

PREVIOUS INTERPRETATIONS

Previous sedimentological interpretations of the Skonun Formation are very generalized. Based on borehole data, Shouldice (1971) reported a regional facies change, from predominantly marine sediments with foraminifera beneath Queen Charlotte Sound, passing northwards into mainly nonmarine deposits with coal beds under Hecate Srait and Graham Island. In detail, however, the northern, onshore boreholes include probable marine intervals (coal-free and shelly) up to 100 m thick (Sutherland Brown, 1968).

According to Sutherland Brown (1968), the Skonun Formation of Graham Island was deposited under alternating marine and nonmarine conditions: "The marine environment is all shallow water, near shore, and the nonmarine is all near sea-level and may include swamp, lagoon, lacustrine, and delta" (Sutherland Brown, 1968, p. 125). Martin and Rouse (1966) visited most of the onshore exposures (Fig. 1) and concluded that deposition took place around "an oscillating shoreline which at intervals flooded coastal swamps or marshes."

The nonmarine intervals of the Skonun Formation were interpreted as entirely lacustrine by Higgs (1988), based upon a perceived lack of evidence for emergence.

Conglomerates at the Cinola gold property on Graham Island were interpreted as braided-stream deposits by Champigny and Sinclair (1982).

COLLISION POINT

Low cliffs at Collison Point (Fig. 1) expose 11 m of poorly indurated horizontal strata dominated by medium sandstone (Fig. 2A). These strata were tentatively dated as Late Miocene to Early Pliocene by Martin and Rouse (1966), based on palynomorphs. A Late Miocene age seems likely, because bivalves of this age occur in sub-horizontal beds, also near sea level, on Kumdis Island 7 km to the northeast (Addicatt, 1978). Bivalves recovered at Collison Point by the author and by Dr. James White during the present study may confirm the age of these strata.

Description

The sandstone is tabular cross-stratified, in sets ranging from 20 to 150 cm thick. Each set is variably reworked by large burrows (Fig. 3). The burrows are *Ophiomorpha* (a branching burrow system dominated by vertical shafts, horizontal tunnels, or a mixture of these and inclined parts; Frey et al., 1978). At Collison Point, shafts and tunnels alike are 0.5 to 4 cm in diameter, with a reinforced lining of sandy mud 0.5 to 1 cm thick. The muddy lining of *Ophiomorpha* is formed by the organism pressing mm-size pellets, composed of sand grains floating in a mud matrix, against the burrow sides, producing the knobby outer wall characteristic of this ichnogenus (Frey et al., 1978). Knobby walls were not detected at Collison Point, however, probably because the burrows do not weather out from their host.

In the interval from 0 to 6.1 m (Fig. 2A), vertical burrow elements predominate (Fig. 3). The burrows are mutually evasive. No branching was observed, but this may simply reflect the two-dimensional nature of the exposure. The burrows descend from the top of each cross-set to a depth of up to 1 m. The foresets in the upper part of each set are completely obscured by closely-spaced burrows (Fig. 3). Burrow density diminishes downward in each set due to 'fallout' of the shallower burrows; in this way, burrowed sand passes downward into asymptotic foresets (Fig. 2A). Foresets invariably dip northward; the exact dip direction is uncertain due to the lack of three-dimensional exposure. The burrows have a mud-free sand fill; this is structureless in most cases, probably introduced by free-fall after burrow abandonment. In other cases the burrow fill shows meniscoid laminae, suggesting active backstuffing by the organism (Fig. 3).

Above 6.1 m, horizontal burrow elements predominate. Cross-sets are burrowed throughout, and set boundaries are difficult to discern. All that remains of the original cross-stratification are small patches of vague foreset laminae

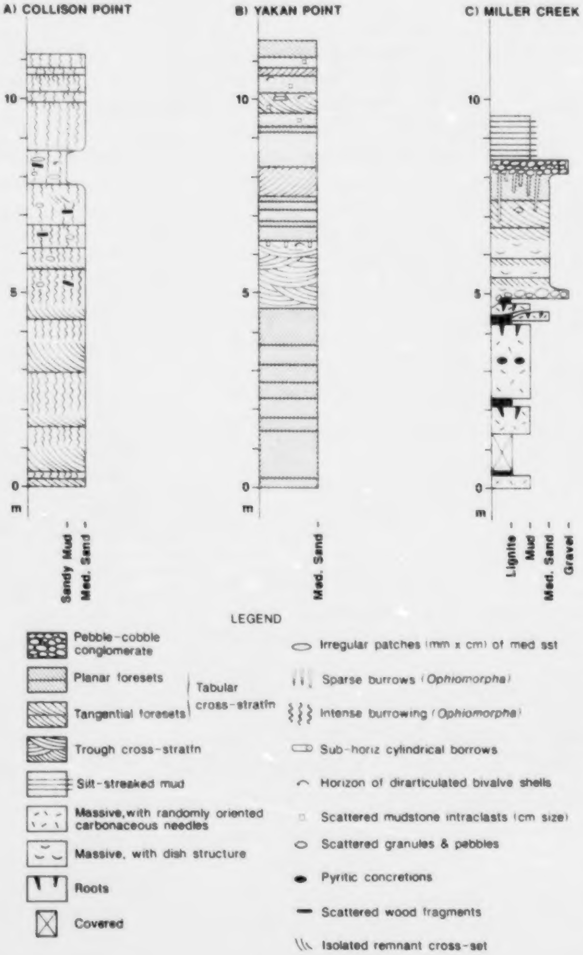
A) COLLISON POINT
B) YAKAN POINT
C) MILLER CREEK
10
5
0
m
Sandy Mud
Med. Sand
Med. Sand
Lignite
Mud
Med. Sand
Gravel
LEGEND
Pebble-cobble conglomerate
Planar foresets
Tangential foresets
Tabular cross-stratfn
Trough cross-stratfn
Silt-streaked mud
Massive, with randomly oriented carbonaceous needles
Massive, with dish structure
Roots
Covered
Irregular patches (mm x cm) of med sst
Sparse burrows (Ophiomorpha)
Intense burrowing (Ophiomorpha)
Sub-horiz cylindrical borrows
Horizon of dirarticulated bivalve shells
Scattered mudstone intraclasts (cm size)
Scattered granules & pebbles
Pyritic concretions
Scattered wood fragments
Isolated remnant cross-set

Figure 2. Measured sections in the Skonun Formation. UTM grid references: Collison Point PQ 829629; Yakan Point UK 146952; Miller Creek UK 032122.

(e.g. Fig. 2A, 7.4 m). Few of the horizontal burrow have any fill; consequently they have been flattened by compaction. The lack of fill means that in this interval the ratio of muddy linings to mud-free sediment is considerably higher than in the lower interval. Due to the higher proportion of mud, the upper beds are darker (grey versus khaki) and less friable than the lower beds. The proportion of muddy burrow-linings in one zone (7.8-8.7 m) is so high that the lithology is essentially sandy mudstone.

Sparse bivalves occur in a 20 cm horizon near the top of the section (Fig. 2A). In addition, wood fragments and isolated 'floating' pebbles are scattered through much of the Collison Point section. The floating clasts are rounded to angular; they include volcanic pebbles and a cobble of schistose, fine-grained amphibolite 14 cm across.

Interpretation

There is no evidence for emergence, suggesting that the entire section was deposited underwater. The floating clasts are not volcanic bombs, because they include amphibolite and some are rounded. The most reasonable explanation is that the clasts are iceberg dropstones, implying deposition offshore, in a sea or lake. The bivalves and burrows are consistent with both interpretations. The tabular cross-sets, formed by migration of straight-crested megaripples, imply a high-energy current. The current was probably of tidal rather than meteorological (wind and wave) origin, because wave-produced sedimentary structures are absent. Hence the inferred environment is a tidal shallow sea floor. The lack of evidence for reversing flow suggests either (1) that the tidal current was strongly asymmetrical (ebb or flood-dominated), perhaps due to an accompanying unidirectional (wind-driven?) current, or (2) that the ebb and flood current-paths were mutually evasise. The megaripples either migrated very slowly or they were widely spaced, allowing time for the back (stoss) of one megaripple to be densely burrowed before burial under the next (advancing) megaripple. The transition from mainly vertical burrows in the lower part of the section to mainly horizontal burrows in the upper part may indicate a decrease in overall current energy (Frey et al., 1978).

The Collison Point section may represent part of a larger-scale tidal sand ridge, similar to the modern linear sand ridges of the North Sea (Kenyon et al., 1981).

YAKAN POINT

Bedrock in a wave-cut platform at Yakan Point (Fig. 1) is largely obscured by loose sand and boulders. However, small tidal pools expose a few decimetres of massive, subhorizontally bedded mudstone with roots and plant fragments, including a fallen tree trunk 6 m long and 1 m across. In contrast, sea stacks along the west side of Yakan Point expose 11 m of well cemented medium sandstone (Fig. 2B), dipping 12° southeast. A fault separates the sea stacks from the aforementioned mudstone exposures, making their stratigraphic relationship uncertain. The sandstone is Late Miocene, based on molluscs and an echinoid (Addicott, 1978).

Description

The sandstone is dominated by tabular crossbedding, with subordinate trough crossbedding (Fig. 2B). Sets range from 15-120 cm thick. Foresets are tangential in some cases and planar in others. Foresets in the interval below 8.2 m dip north; in contrast, foresets in the overlying interval dip south (Fig. 4), with a few interspersed north-dipping sets forming herringbone cross-stratification. Two coquina beds up to 5 cm thick, consisting of convex-up bivalve shells, occur in the upper interval. Vertical and horizontal *Ophiomorpha* burrows up to 10 cm in diameter occur locally, as well as scattered angular mudstone clasts up to 3 cm across.

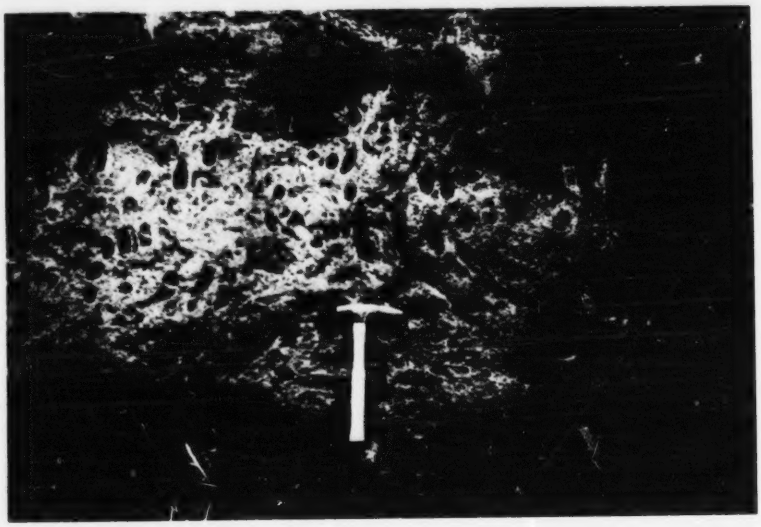

Figure 3. Cliff face, perpendicular to bedding, showing dense *Ophiomorpha* burrows in medium sandstone at Collison Point (Fig. 2A, 1.9-2.9 m). Vertical shafts are dominant. The reinforced burrow-lining, consisting of stiff sandy mud, stands out clearly. One burrow shows a meniscate backfill (upper right).

Interpretation

The opposed foresets indicate paleocurrent reversals and therefore suggest tidal currents. This implies a marine environment, as does the echinoid discovered by Addicott (1978). The echinoid, and the lack of evidence for emergence, suggest a subtidal setting. In the absence of lateral accretion surfaces, characteristic of tidal inlets, deposition probably took place on a tidal delta or in an offshore, tidal-shelf environment. This is consistent with the presence of *Ophiomorpha*, which is probably a crustacean burrow (Frey et al., 1978).

The cross-sets were formed by migrating megaripples, with sinuous crestlines in the case of the trough cross-sets. The paleoflow reversal evident at 8.2 m indicates a change from ebb- to flood-tidal dominance, or vice versa. This implies that the ebb and flood currents followed mutually evasive paths.

The coquina beds are interpreted as winnowed lag accumulations, comprising shells whose original host sediment was eroded by tidal or meteorological currents. The host sediment could have been mud, since the shell beds are closely associated with mudclasts (Fig. 2B).

The rooted mudstone exposed elsewhere at Yakan Point (see above) is probably an alluvial- or delta-plain overbank deposit. Similar facies are better exposed at Miller Creek.

MILLER CREEK

Ten metres of sandstone, mudstone and coal (lignite) are exposed in the stream-bank at the mouth of Miller Creek on the east coast of Graham Island (Figs. 1, 2C). These strata dip about 10° to the west. The age of the Miller Creek section is uncertain. Martin and Rouse (1966) tentatively assigned a Late Miocene or Early Pliocene age, based on palynomorphs. The structural dip and the advanced state of lignite compaction lend support to a pre-Pleistocene age. Three facies were recognized in the Miller Creek section.

Facies 1. Interbedded mudstone and coal

Description

This facies comprises the bottom 5 m of the section (Fig. 2C) and consists of lignite beds up to 20 cm thick alternating with massive grey mudstone layers. Within the lignite beds, tree trunks, branches and stumps can be recognized. The mudstone layers contain oblique roots 0.5-5 cm in diameter and at least 30 cm long. The mudstone also contains abundant randomly oriented carbonaceous needles about 1 mm in diameter and up to 1 cm long. One mudstone layer contains a horizon of disconnected, cm-size pyritic concretions. The lignite bed at 4.3 m envelops a convex-up lens of massive, rooted, medium sandstone, 5 m across and up to 25 cm thick.

Interpretation

The coal beds are autochthonous, as shown by the presence of roots, suggesting that the depositional environment was emergent or near-emergent. The associated mudstone layers lack soil profiles, suggesting that they are swamp deposits rather than paleosols. In support of this interpretation, Martin and Rouse (1966) reported that pollen and spores from swamp-dwelling trees occur in the Miller Creek mudstones and coal beds. A swamp environment implies a high water table and a very low gradient, suggesting an alluvial- or delta-plain overbank setting. The pyritic concretions may indicate a brackish or marine influence (e.g. Berner, 1983), consistent with a delta-plain setting. The lenticular sandstone layer was probably deposited by flood waters breaching a distributary levee. The massive texture of the mudstones may reflect destruction of original lamination by root growth.

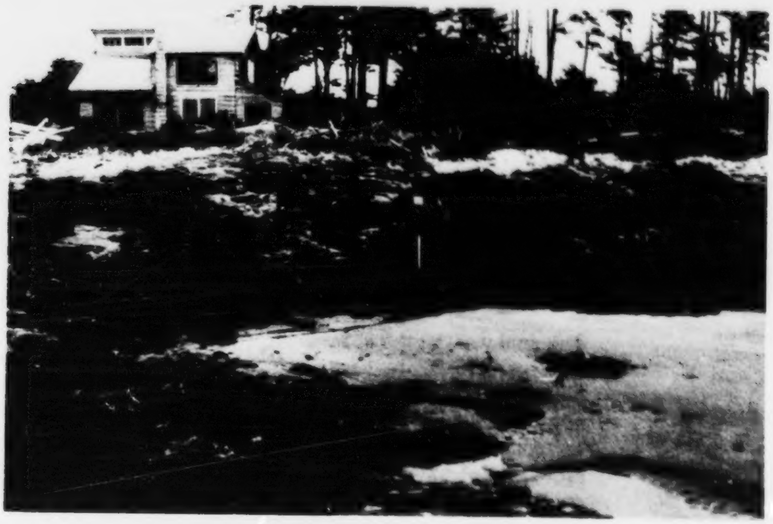

Figure 4. Sea stack and adjacent platform at Yakan Point, showing tabular crossbedded sandstone, dipping gently to the right and into the picture (southeast). A prominent set boundary is visible at James White's mid-thigh level (Fig. 2B, 8.2 m). Note that all visible foresets below this level dip to the left (north), whereas all foresets above this level dip to the right. (The opposed dips are especially well displayed at the extreme left-centre of the photograph.)

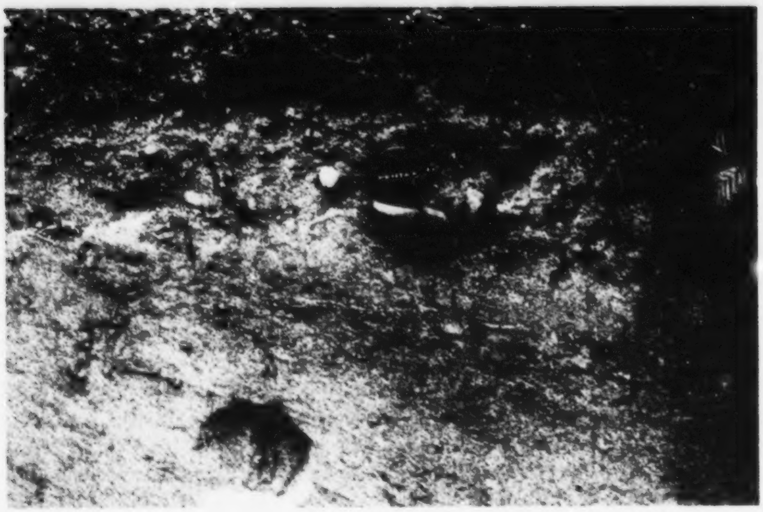

Figure 5. Sandstone containing dispersed "floating" granules and pebbles, interpreted as dropstones. The clasts become more concentrated upwards. Note the subrounded granitoid pebble immediately left of the lens cap. Faint foreset laminae are visible in the lower half of the photograph, dipping to the right. Miller Creek (Fig. 2C, 7.7-8.1 m). Lens cap is 5.3 cm in diameter.

Facies 2. Cross-stratified sandstone

Description

This facies consists of tabular cross-stratified medium sandstone, and constitutes the interval 4.9 to 8.4 m. The base is a gently concave-up scour showing 20 cm of relief over a lateral distance of a few metres. The scour locally removes the uppermost coal bed (Fig. 2C). Five cross-sets are present, ranging from 40-80 cm thick. Foresets are tangential, but are insufficiently exposed for paleocurrent determination. Set boundaries are planar but not quite parallel, adjacent pairs diverging by up to 20°. In the bottom three sets, the cross-laminae grade downward into massive sandstone with dish structures.

A layer of rounded to angular pebbles and cobbles, one clast thick, occurs at the base of the Facies 2 interval. The clasts, which include volcanics and granitoids, are up to 50 cm across. Between the clasts, the basal centimetre of the Facies 2 interval consists of pyrite-cemented sandstone.

Floating volcanic and granitoid clasts are scattered throughout the sandstone (Fig. 5). The clasts are angular to rounded and are up to 30 cm across. Clast concentration increases markedly near the top of the sandstone unit, such that the sandstone grades upward over a thickness of some 20 cm into a clast-supported conglomerate layer (Figs. 2C, 5). The conglomerate layer is 35 cm thick, poorly sorted, ungraded and unstratified.

Sparse *Ophiomorpha* burrows up to 1.4 m long descend from the top of the Facies 2 interval.

Interpretation

The floating clasts are interpreted as iceberg dropstones, implying that Facies 2 was deposited offshore, in a sea or lake. In the absence of wave-formed sedimentary structures, Facies 2 is more likely to have been deposited by tidal currents than by meteorological currents. An alternative possibility is that Facies 2 represents subaqueous glacial outwash, deposited by meltwater issuing from a subglacial channel (e.g. Edwards, 1986). This is unlikely, however, because dropstones are rare in subaqueous outwash due to high sedimentation rates (Edwards, 1986). Hence the depositional environment was probably a tidal sea floor.

The thickness and geometry of the cross-sets suggests that the bedforms responsible were relatively straight-crested megaripples. The origin of the massive intervals with dish structure is problematical. The pebble-cobble layer at the base of the sandstone unit is attributed to winnowing of dropstones formerly dispersed in sand, by strong (storm-enhanced?) tidal currents. A similar origin is invoked for the conglomerate layer at the top of the sandstone unit.

Facies 3. Lenticular-bedded mudstone

Description

Facies 3 constitutes the top 1.2 m of the Miller Creek section and consists of grey mudstone with streaks and ripples of siltstone and fine sandstone. The ripples occur as trains of disconnected individuals up to 3 mm thick. The ripples are asymmetrical and seldom show internal lamination. The streaks and ripples recur at irregular vertical intervals of 1-5 mm. Facies 3 strongly resembles the 'Lenticular bedding... with single flat lenses' of Reineck and Wunderlich (1968, their fig. 5). The base of the Facies 3 interval is sharp and the top is not exposed.

Interpretation

The mud was deposited from suspension, whereas the sand ripples represent higher-energy tractional episodes. The higher-energy currents may have been tidal currents, density underflows or wind-driven currents. However, tidal currents are the most likely, in view of the association with crossbedding of inferred tidal origin (Facies 2). There is no evidence for emergence, suggesting a subtidal environment. The presence of mud indicates deposition below fair-weather wavebase. Hence, like Facies 2, the interpreted environment is a tidal sea floor.

Facies sequence

The vertical sequence at Miller Creek is transgressive, with inferred delta-plain sediments overlain by shallow-marine deposits. The lack of any intervening shoreline or delta-front sediments suggests either that the transgression was very sudden, due to an episode of rapid subsidence or sea-level rise, or that the transgression caused erosional shoreface retreat (Elliott, 1986), in which case the sharp contact between facies 1 and 2 represents a significant erosion surface.

Offshore tidal sands of Facies 2 are sharply overlain by offshore tidal muds of Facies 3 (Fig. 2C). This suggests a sudden diminution of tidal energy. Possible causes include (1) sudden deepening of the environment due to accelerated subsidence or sea-level rise; (2) a tectonically induced change in basin configuration, causing a change in the tidal characteristics; and (3) lateral shifting of the tidal flow path.

DISCUSSION

Implications for petroleum exploration

Tide-dominated offshore facies occur at all three localities. Hence, the marine intervals in the subsurface of the Queen Charlotte Basin may contain similar facies, including tidal sand ridges with reservoir potential. Linear tidal sand ridges tens of kilometres long, kilometres wide, and 5-50 m thick are well known in modern and ancient subtidal deposits (e.g. Johnson and Baldwin, 1986). Stacked coarsening-upward sand bodies between 5900 and 6800 feet in the Harlequin offshore well could be tidal sand ridges.

Similarly, the recognition of delta-plain facies, as at Miller Creek, suggests that distributary channels may occur in the subsurface. Progradational delta-front sands might also be present; these would be linear, shore-normal bodies if the deltas were tide-dominated, or sheet-like bodies if the deltas were wave-influenced (Elliott, 1986).

Paleoclimatic implications

The suggested presence of ice-rafted dropstones in the Collison Point and Miller Creek sections indicates that icebergs were calving nearby, presumably along the coast of mainland British Columbia, southeasternmost Alaska, or perhaps an ancestral Queen Charlotte landmass. If the Collison Point section is of Late Miocene age, as speculated above, the implication is that glaciers reached the sea hereabouts as early as Late Miocene time. Support for such early glacial activity is given by the author's observation of dropstones at Skonun Point, 15 km west of Yakan Point (Fig. 1), in sandstone dated as Late Miocene by Addicott (1978). Further support comes from the presence of dropstones in Upper Miocene strata of southeastern Alaska (Plafker and Addicott, 1976): these strata belong to the south-derived Yakutat allochthonous terrane, and probably lay closer to the Queen Charlotte Islands in Late Miocene time (cf. Bruns, 1983; Plafker, 1984). Notwithstanding the dropstones, molluscs in the Skonun Formation indicate that the Late Miocene climate was temperate and 'probably somewhat warmer than ... today' (Addicott, 1978, p. 687). Similarly, the microflora of the Skonun Formation indicates that the climate was 'relatively humid, and probably somewhat more temperate' than today (Martin and Rouse, 1966, p. 179). Thus the dropstones probably do *not* reflect a cold climate; this is consistent with the close association of dropstones and coal beds at Miller Creek. Instead, the dropstones may reflect a combination of high elevations and heavy precipitation in the Coast Mountains of mainland British Columbia opposite the Queen Charlotte Islands. In Late Miocene time these mountains were higher than at present, due to a burst of rapid uplift (Parrish, 1983).

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I thank James White for helpful discussion and pleasant companionship in the field, and Steve Harding (Husky Oil) for suggesting, by telephone, that the large burrows might be *Ophiomorpha*. James White and John Clague kindly discussed the significance of the dropstones with me, but do not necessarily agree with my interpretation. Ken Hoffman provided capable and cheerful field assistance. I am grateful to Gena L'Esperance for her meticulous drafting.

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Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia[1]

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Anderson, R.G. and Greig, C.J., Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 95-104, 1989.

Abstract

Two Late Jurassic (145-160 Ma) and one Tertiary (24-40 Ma) plutonic suites define calc-alkaline, I-type plutonism, distinguished by plutonic and structural styles: the San Christoval plutonic suite (SCPS); the Burnaby Island plutonic suite (BIPS); and Tertiary Kano plutonic suite (KPS).

SCPS is foliated diorite and quartz diorite with deformed inclusions but few dykes. BIPS is unfoliated gabbro, diorite, quartz monzodiorite, quartz monzonite and trondjhemite with fractures and veins. BIPS crosscuts Middle Jurassic and older strata and is overlain by Lower Cretaceous Longarm Formation. Late Jurassic to Early Cretaceous alteration of the Kunga Group produced copper-iron skarns.

KPS occurs as two northwest-trending, subparallel belts of northerly time-transgressive (quartz) monzodiorite and lesser diorite and granite. The oldest plutons in KPS are bimodal or are characterized by north-trending, intraplutonic (opx-bearing) porphyritic dykes and stocks and indicate Late Eocene extension.

Résumé

Deux suites plutoniques de la fin du Jurassique (145 à 160 Ma) et l'une du Tertiaire (24 à 40 Ma) définissent le plutonisme calco-alcalin de type I qui se distingue par ses styles plutoniques et structuraux: la suite plutonique de Sans Christoval, la suite plutonique de Burnaby Island et la suite plutonique tertiaire de Kano.

La suite plutonique de San Christoval se compose d'inclusions déformées, mais de rares dykes, de diorite et de diorite quartzique feuilletées; la suite plutonique de Burnaby Island de gabbro, de diorite, de monzodiorite quartzique et de trondjhémite non feuilletés, fracturés et veinés. La suite plutonique de Burnaby Island recoupe des couches du Jurassique moyen et plus anciennes et est recouverte par la formation de Longarm du Crétacé inférieur. L'altération du groupe de Kunga de la fin du Jurassique au début du Crétacé a produit des skarns avec cuivre et fer.

La suite plutonique tertiaire de Kano prend la forme de deux zones d'orientation nord-ouest subparallèles de monzodiorite et de quantités moindres de diorite et de granite transgressives (quartz) en fonction du temps et en direction du nord. Les plus anciens plutons de la suite plutonique tertiaire de Kano sont bimodaux ou caractérisés par des dykes et des stocks intraplutoniques (renfermant de l'opx) porphyriques d'orientation nord et indiquent une extension à la fin de l'Éocène.

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INTRODUCTION

Granite plutons make up about 1000 km^2 or 10 % of the area of the Queen Charlotte Islands and the plutonism spans about 140 of its 250 million year geological history. Late Jurassic (145-166 Ma) and Tertiary (24-44 Ma) plutonism occurred at important intervals in the terrane's geological evolution and is a significant constraint in evaluation of the islands' hydrocarbon potential.

New field mapping suggests an objective division of Jurassic and Tertiary plutons into suites (Anderson, 1988a, b, and c; Anderson et al., 1988) based on elements of their plutonic style: composition, mineralogy, texture and fabric, geophysical signature, mafic inclusion and dyke abundance and intrusive and geological relationships. Hornblende K-Ar and zircon U-Pb geochronometry is underway to improve regional coverage and to date critical intrusive events (e.g. Anderson and Reichenbach, 1989). Divergence from an earlier tectonic granite classification (Sutherland Brown, 1968) was reviewed by Anderson (1988a, b, and c) and derives from: reinterpretation of structural fabric in some plutons; isotopic age data (Young, 1981); and reinvestigation of critical geological relationships. Division of Late Jurassic plutons into two groups, the coeval San Christoval (SCPS) and Burnaby Island (BIPS) plutonic suites, and inclusion of eastern and western Tertiary plutons into the Kano plutonic suite (KPS; Anderson et al., 1988) emphasizes intrasuite similarities and intersuite differences (Fig.1).

Mapping in 1988 refined the distribution and criteria for the plutonic suite subdivision and the results may be summarized as follows:

1. Late Jurassic (145-166 Ma) and Oligocene (24-44 Ma) plutonic suites are best distinguished on grain size (KPS the finest grained), heterogeneity and degree of alteration (BIPS the most heterogeneous and altered), fabric and dyke abundance (SCPS the most extensively foliated and dyke-poor), and hornblende crystallinity (prismatic hornblende is typical of SCPS).
2. Overmaturation of Kunga Group on southeastern Moresby Island (Orchard, 1988) may be caused by: a) Late Jurassic to Early Cretaceous circulation of hydrothermal fluids associated with BIPS which fostered cospatial Fe-Cu skarns (Anderson, 1988c); and/or b) Eocene, extension-related, bimodal plutonism, north-trending dyking, and minor hydrothermal alteration which may herald opening of the Queen Charlotte basin around 40-44 Ma (Anderson and Reichenbach, 1989).

GEOLOGY OF THE COUNTRY ROCKS

Aspects of the country rock geology relevant to Jurassic and Tertiary plutonism were reviewed in Anderson (1988a). The emphasis in this review is on the plutonic styles of the San Christoval, Burnaby Island and Kano plutonic suites.

LATE JURASSIC (145-166 Ma) PLUTONIC SUITES

Late Jurassic (145-166 Ma (K-Ar); Anderson and Reichenbach, 1989) plutons are divided into the San Christoval plutonic suite (SCPS) which occurs on the west coasts of Moresby and Graham islands and the Burnaby Island plutonic suite (BIPS) distributed on the islands' east coasts. SCPS is characteristically homogeneous diorite and quartz diorite, inclusion-rich and foliated (Sutherland Brown's (1968) "syntectonic" plutons). BIPS plutons are typically heterogeneous (comprising gabbro, diorite, quartz monzodiorite, quartz monzonite and trondhjemite (leucodiorite)), unfoliated and pervasively brittly fractured and veined. BIPS crosscuts Middle Jurassic and older strata and is nonconformably overlain by Lower Cretaceous Longarm Formation. Hydrothermal alteration of the Kunga Group is coincident with intrusion of the suite.

San Christoval plutonic suite (SCPS)

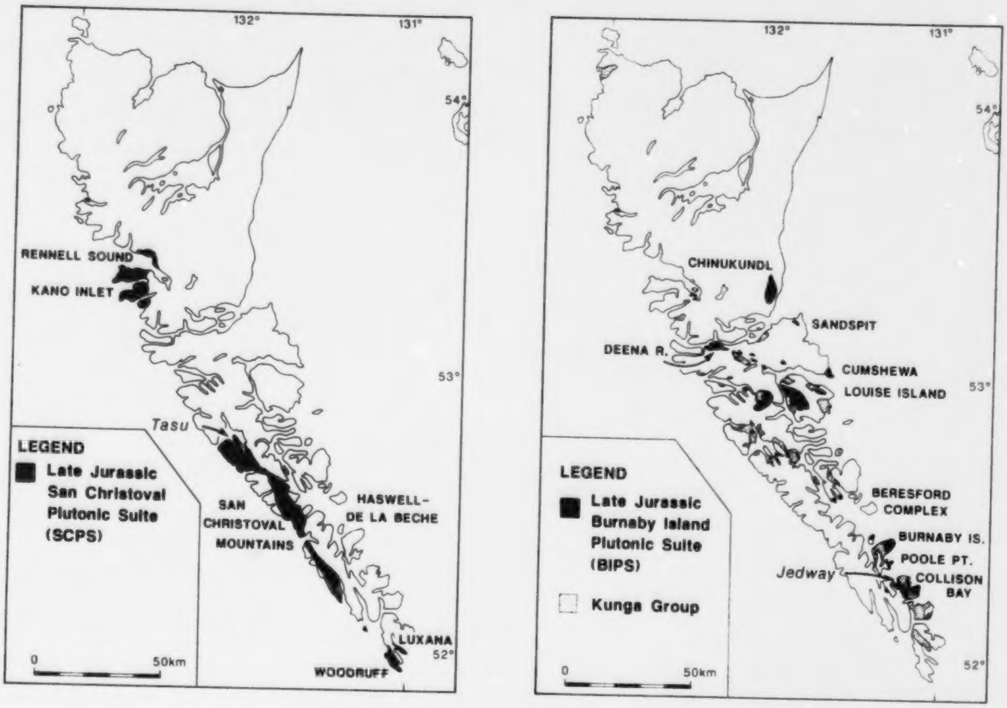
San Christoval plutonic suite outcrops in three areas (Fig. 1): Woodruff and Luxana bays in the south (32 km^2); San Christoval Mountains (390 km^2) in its central part; and Rennell and Kano inlets (at least 105 km^2) to the north. The northern and southern areas have been studied in most detail; transects along Haswell Bay-de la Beche Inlet and along Bigsby Inlet and limited reconnaissance of San Christoval Mountains provided information about the central portion of the suite. SCPS extends farther east in Kano Inlet (at least to Givenchy Anchorage) and probably farther east in Van Inlet than was previously thought.

Although SCPS is lithologically homogeneous, the aeromagnetic signature of its regional total field varies from high values in the north and south parts (56 300-57 000 and 56 200-56 900 gammas) to lower values in the central part/(56 000-56 500 gammas; Geological Survey of Canada, 1987b, c, and e). The suite's specific gravity profile (Fig. 3; median specific gravity of 2.75) is more representative of the suite's homogeneity.

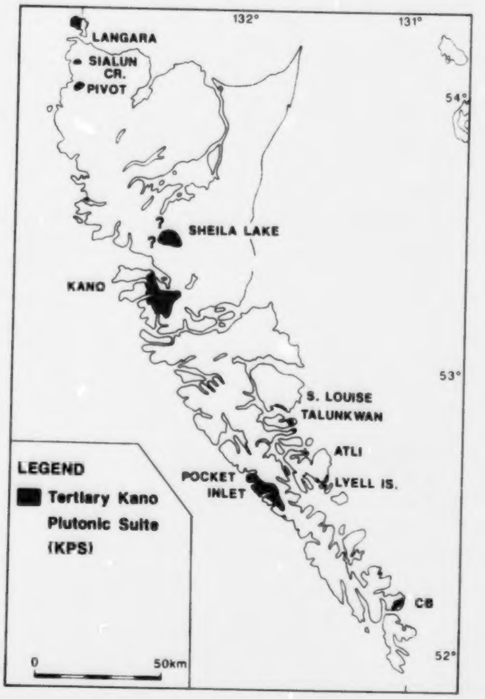
SCPS is the most compositionally monotonous of the three suites (Fig. 2). Hornblende monzodiorite, quartz monzodiorite and minor (quartz) diorite dominate. Hornblende is typically prismatic; biotite is scattered throughout the suite and is poikiloblastic and preferentially chloritized compared with hornblende. Magnetite occurs rarely and titanite (sphene) is conspicuously absent.

Two exceptions to the overall homogeneity of SCPS are the heterogeneous zones at Kindakun and Hunter points at the mouth of Kano Inlet and at Sac Bay in de la Beche Inlet. Heterogeneous, foliated hornblende diorite stockworks and agmatite at Kano Inlet are developed in fine grained diorite or amphibolite (mapped as Jsm by Sutherland Brown (1968)). The mafic complex is intruded by massive gabbro or diorite, monzodiorite and monzonite phases within the complex and is likely intruded by massive, homogeneous SCPS along the margins of the intrusive complex. The composition, intrusive relations and fabric in the Hunter-Kindakun points complex are closely similar to the Beresford complex described with BIPS.

At Sac Bay, an early massive diorite phase (dated by K-Ar method at 166 ± 3 Ma; Anderson and Reichenbach, 1989) is intruded by foliated quartz diorite whose foliation trends deflect into parallelism with the contact.



132°
131°
54°
53°
52°
RENNELL SOUND
KANO INLET
Tasu
SAN CHRISTOVAL MOUNTAINS
HASWELL-DE LA BECHE
LUXANA
WOODRUFF
LEGEND
Late Jurassic San Christoval Plutonic Suite (SCPS)
0
50km
132°
131°
54°
53°
52°
CHINUKUNDL
SANDSPIT
DEENA R.
CUMSHEWA
LOUISE ISLAND
BERESFORD COMPLEX
BURNABY IS.
POOLE PT.
Jedway
COLLISON BAY
LEGEND
Late Jurassic Burnaby Island Plutonic Suite (BIPS)
Kunga Group
0
50km



132°
131°
54°
53°
52°
LANGARA
SIALUN CR.
PIVOT
?
?
SHEILA LAKE
KANO
S. LOUISE
TALUNKWAN
ATLI
POCKET INLET
LYELL IS.
CB
LEGEND
Tertiary Kano Plutonic Suite (KPS)
0
50km

Figure 1. Distribution of Late Jurassic and Tertiary plutonic suites in Queen Charlotte Islands. Names refer to informal pluton names used in text (CB = Carpenter Bay). Distribution of Upper Triassic-Lower Jurassic Kunga Group, a possible source rock for hydrocarbons, is shown on the Burnaby island plutonic suite distribution.

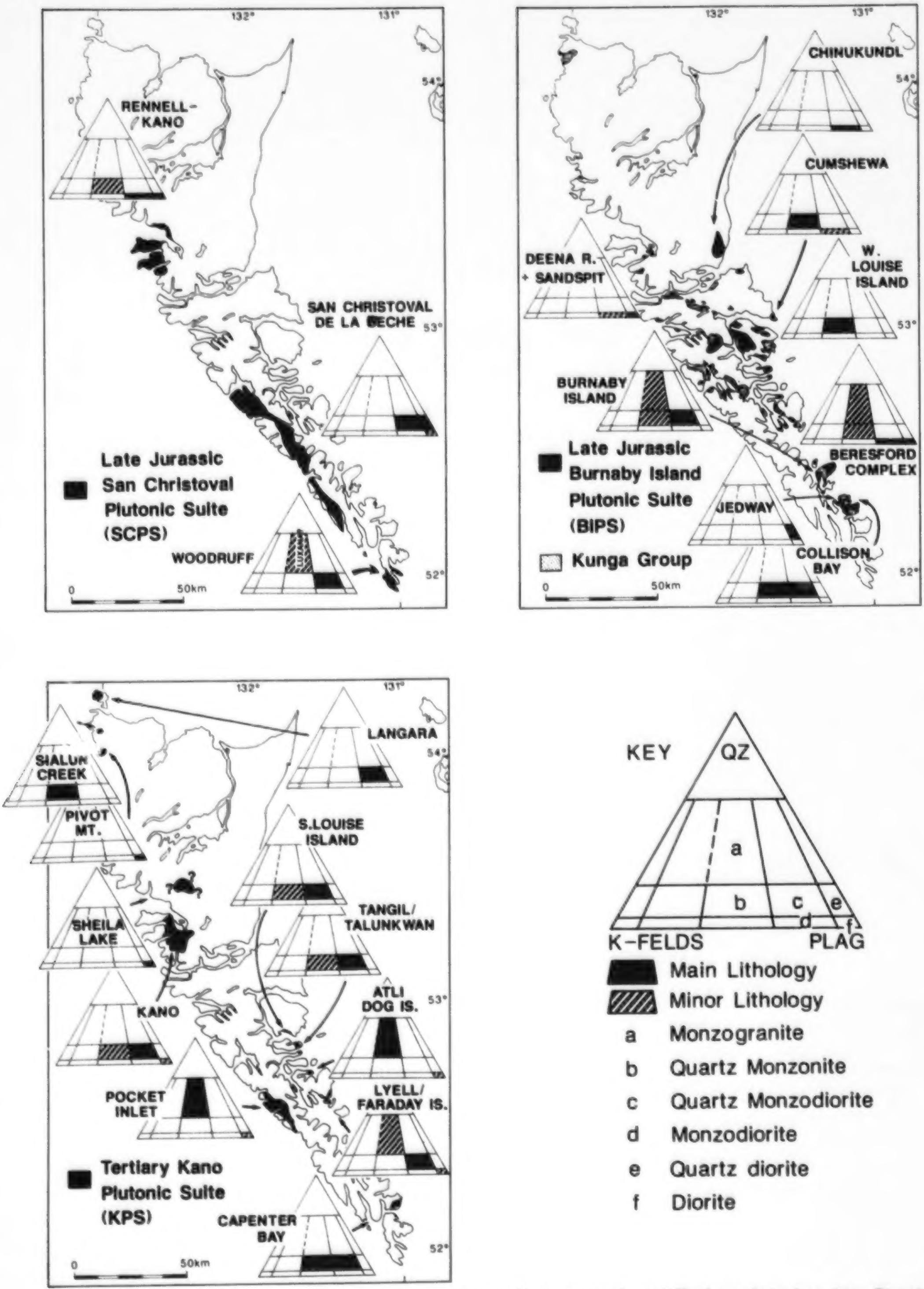

132°
131°
54°
53°
52°
RENNELL-KANO
SAN CHRISTOVAL DE LA BECHE
WOODRUFF
Late Jurassic San Christoval Plutonic Suite (SCPS)
0
50km
CHINUKUNDL
CUMSHEWA
DEENA R. + SANDSPIT
W. LOUISE ISLAND
BURNABY ISLAND
BERESFORD COMPLEX
JEDWAY
COLLISON BAY
Late Jurassic Burnaby Island Plutonic Suite (BIPS)
Kunga Group
LANGARA
SIALUN CREEK
PIVOT MT.
S.LOUISE ISLAND
SHEILA LAKE
TANGIL/ TALUNKWAN
KANO
ATLI DOG IS.
POCKET INLET
LYELL/ FARADAY IS.
Tertiary Kano Plutonic Suite (KPS)
CAPENTER BAY
KEY
QZ
a
b
c
d
e
f
K-FELDS
PLAG
Main Lithology
Minor Lithology
a Monzogranite
b Quartz Monzonite
c Quartz Monzodiorite
d Monzodiorite
e Quartz diorite
f Diorite

Figure 2. Compositional spectrum among members of Late Jurassic and Tertiary plutonic suites. Streckeisen's (1973) quartz/alkali-feldspar/plagioclase classification is used.

Compared to other suites, SCPS is inclusion-rich and the inclusions are commonly foliated. Fine grained, equigranular or hornblende porphyry diorite inclusions 5-15 cm long make up 1-2 % (locally up to 50 %) of the rock. Oblate inclusions, and less commonly, hornblende mineral foliation define a subvertical planar fabric which characterizes SCPS throughout its breadth. The foliation gave rise to the "syntectonic" designation for SCPS by Sutherland Brown (1968). Although the foliation is a useful mapping criterion to distinguish SCPS, field evidence suggests it is primary, not superimposed (Anderson, 1988a). The foliation is best developed within 0.5-1 km of intrusive contacts with the Karmutsen Formation (as in the de la Beche-Haswell, Bigsby, and Woodruff Bay transects). Variations in trend mirror the orientation of intrusive contact and, locally, as in the Rennell-Kano part of SCPS, variations in the strike of the overall north-trending foliation are apparently random. The variations suggest that the foliation has a primary magmatic origin, developed in response to local, intrusion-induced, compressional stress rather than to a superimposed, post-intrusion deformation. Exceptions are the mylonitic fabrics developed in Sutherland Brown's (1968) Jsm unit at Luxana Bay (Sutherland Brown, 1968: Anderson, 1988a).

Brittle fracture and alteration zones, typical of BIPS, are rare in the southern and central parts of SCPS but are common in Rennell Sound and Kano Inlet. The zones share many of the characteristics of BIPS zones (see below) but the veins are more variably oriented regionally and less continuous at outcrop scale than in BIPS. Sutherland Brown (1968) mapped some of these zones as intraplutonic faults. The zones are certainly the locus of pervasive, (even penetrative) brittle fracture and veining; however, there is rarely a consistent fracture or vein orientation throughout a zone. They probably represent areas of local hydro-fracture rather than important regional faults.

Upper Triassic Karmutsen Formation hosts SCPS along most of its breadth. However, Upper Triassic and Lower Jurassic Kunga Formation is the youngest unit intruded and, locally, important iron-copper skarns are developed in the volcanic rock and limestone at the intrusive contact (e.g. Tasu; Sutherland Brown, 1968). Skarns and alteration-fracture zones, while abundant in and typical of BIPS, are not restricted to that suite.

Dykes are uncommon in SCPS, particularly in the southern and central parts. At Rennell Sound and Kano Inlet, basalt, andesite and lesser felsic dykes form part of the predominantly north-northeast to east-trending Rennell dyke swarm (Souther, 1988; Souther and Bakker, 1988). Columnar-jointed basalt dykes prominent in SCPS along much of Rennell Sound and Kano Inlet are not seen in the cospatial Oligocene Kano pluton (dated at 32 Ma; Young, 1981; Anderson and Reichenbach, 1989).

Potassium-argon isotopic ages for SCPS hornblende vary from 146-166 Ma (see Anderson, 1988a and Anderson and Reichenbach, 1989 for review). The oldest cooling age, 166 ± 3 Ma, gives the best estimate for intrusion of the suite.

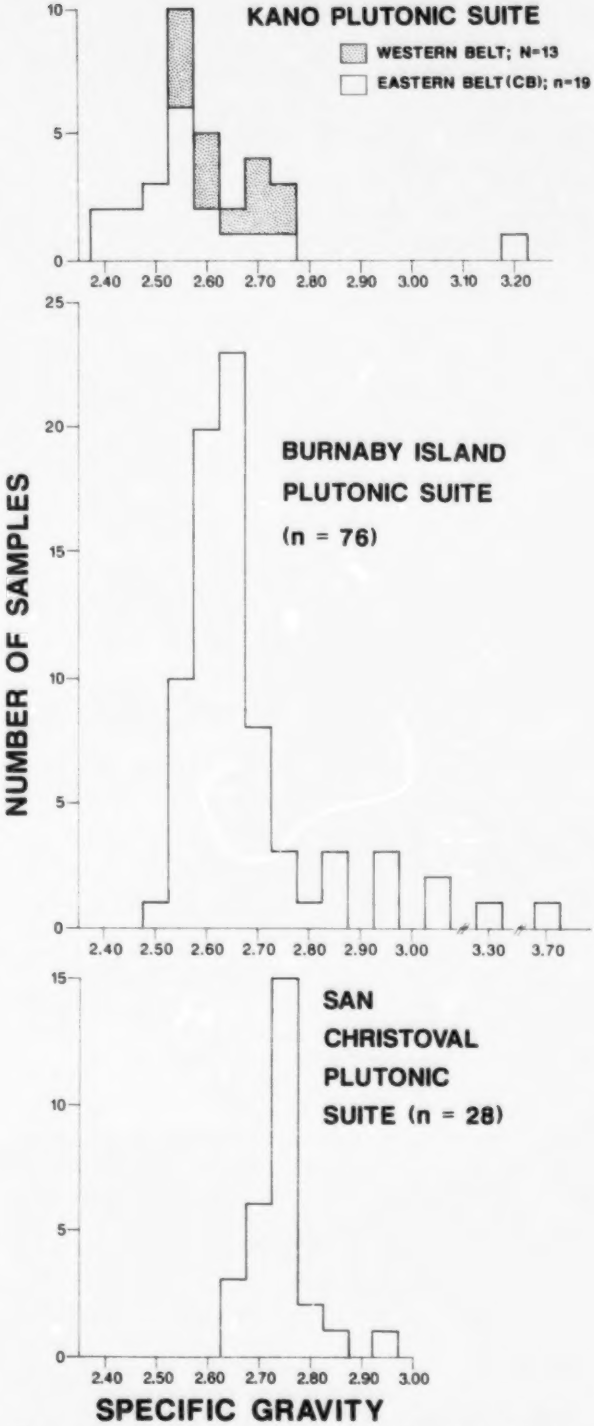


Figure 3. Specific gravity of samples from Late Jurassic and Tertiary plutonic suites.

Burnaby Island plutonic suite (BIPS)

Burnaby plutonic suite is the eastern belt of Late Jurassic plutons and includes (Fig. 1): Chinukundl (23 km^2), Sandspit (2 km^2), Deena River (6 km^2), Cumshewa (11 km^2), western Louise Island (58 km^2), Sewell Inlet (16 km^2), Beresford Complex (2 km^2), Burnaby Island (17 km^2), Poole Point (2 km^2), Jedway (3 km^2), and Collison Bay (3 km^2) plutons. All plutons except Sewell Inlet pluton were examined. Deena River and Sandspit plutons have some characteristics in common with Kano plutonic suite and inclusion in BIPS (Figs. 1 and 2) may not be correct. The Beresford complex is closely similar to the Kindakun Point-Hunter Point complex included with SCPS; it is included in BIPS because it is cospatial with other plutons in the suite and contains trondhjemite phases unique to BIPS. However, the deformed mafic complex may define the easternmost extent of SCPS much as the Kindakun Point-Hunter Point complex seems to define part of the suite's western margin.

The aeromagnetic signature of BIPS (total field values of 56 400-56 900 gammas; Geological Survey of Canada, 1987b, d, and e) is not as distinctive as previously thought. Positive aeromagnetic anomalies up to 400 gammas in relief, centred over some BIPS plutons (e.g. Chinukundl, Sandspit, Cumshewa, Burnaby Island and Poole Point plutons), are also underlain by plutons now known to be Tertiary. Specific gravity values (Fig. 3) are distinctive of BIPS in median value (2.65) and in wider variance than other suites reflecting the overall heterogeneity of BIPS.

Compositional heterogeneity of individual plutons and of the suite as a whole is a mark of BIPS (Fig. 2). Composite plutons may contain two or more phases of: biotite-hornblende (quartz) monzodiorite (most common); hornblende-biotite quartz monzonite; hornblende quartz diorite; (hornblende-) clinopyroxene gabbro or hornblende diorite; and chloritized biotite or muscovite trondhjemite or leucodiorite (least common). Phases were intruded in mafic to felsic order. The rocks are massive (except for Beresford complex), equigranular and medium-grained (finer-grained than SCPS but coarser grained than KPS). Hornblende is subhedral and biotite less altered compared with SCPS. Titanite or magnetite rarely are present. Subround mafic inclusions are important but scattered throughout the suite (1-2 % of the rock), small (5-10 cm across), unoriented and usually occur in monzodiorite phases.

Beresford complex includes Sutherland Brown's (1968) Jsm unit along Richardson Point, Beresford Inlet and northwestern Sedgwick Bay. The complex is defined by heterogeneous, inclusion-rich, foliated mafic hornblende diorite, diorite agmatite and diorite stockworks in foliated amphibolite. Massive diorite, gabbro, monzodiorite, quartz monzonite and trondhjemite (leucodiorite) phases intrude the foliated mafic rocks. Mafic mineral fabric characterizes: subvertical northwest-trending foliation; rare, decimeter-scale, coplanar mylonite zones in and near Beresford Inlet; and rare subvertical south-plunging lineation. Variably-oriented brittle faults overprint the ductile fabric and separate the complex from Karmutsen Formation rocks at one locality. Except for scattered mylonitic rocks in Beresford Inlet, concordance of the complex's structural grain with external contacts and its steeply plunging lineation suggest a syn-intrusive origin for the mineral fabric.

The affinity of the Beresford complex is unclear. The foliated parts of the complex resemble SCPS in mineralogy, inclusion abundance and structural grain. The later, massive phases compare closely with BIPS in compositional spectrum, alteration and unfoliated nature. Occurrence of the trondhjemite phase is apparently restricted to the Beresford complex and Burnaby Island pluton.

Burnaby Island plutonic suite was emplaced between the Bajocian and Early Cretaceous time. It intrudes Bajocian (Yakoun Formation) and older rocks and is nonconformably overlain by Lower Cretaceous Longarm Formation. The nonconformity is best exposed near Rebecca Point where intensely-altered hornblende monzodiorite of the Poole Point pluton is overlain by comparatively unaltered, greenish brown greywacke and pebble to granule conglomerate of the Longarm Formation. At least 3 m of relief is represented by the nonconformity. *Inoceramus colonicus* fauna in Poole Inlet (Sutherland Brown's (1968, Figure 78) fossil-map number 2) indicate that the strata belong to the Longarm Formation. The break is important in establishing a minimum stratigraphic age for BIPS and for the intense hydrothermal alteration associated with the suite. Circulation of hydrothermal fluids outward into the country rock may be partly responsible for high conodont colour alteration indices (Orchard, 1988) in nearby Kunga Group limestone.

Green, aphanitic to plagioclase-, biotite-, hornblende- and/or clinopyroxene-phyric felsic, intermediate and mafic dykes intrude BIPS. The compositional range, phenocryst mineralogy and orientation of the dykes suggest that some, if not all, are part of the Tertiary Burnaby Island-Carpenter Bay dyke swarm (Souther, 1988; Souther and Bakker, 1988; Anderson and Reichenbach, 1989). Although the dykes are apparently unrelated to the plutons and crosscut the pervasive veining, common margin-parallel veins are developed in the andesite dykes. One distinctive and important class of dyke, a green and black flow-layered pyroxene-rich basalt, is best exposed at the classic sub-Longarm Formation unconformity on Arichika Island. These "Arichika" dykes post-date all veining in BIPS.

Perhaps the most striking feature of the BIPS is the closely-spaced, continuous vein sets which crosscut the plutons. Calcite, chlorite, epidote, quartz, alkali-feldspar and gypsum(?), in decreasing abundance, fill the veins. Calcite postdates the propylitic assemblage. A pink, potassic(?) alteration of the plutons within 2-10 cm of chlorite-epidote veins is common. Gabbro or diorite phases on Burnaby and Alder islands localize garnet-epidote endoskarn.

There is considerable scatter in the orientation of predominantly subvertical veins. Generally, early north- and east-trending veins are crosscut and/or displaced by steep northeast- and southeast-trending veins. In the Poole pluton, subhorizontal veins of various trends are important. Most of the hydrothermal alteration of BIPS pre-dates deposition of the Lower Cretaceous Longarm Formation. Crosscutting relationships between veins and dykes indicate that most veins also predate the dykes; however, veining occurs along dyke margins and there is evidence for reactivation of earlier vein directions after dyke emplacement. Discontinuous, irregular calcite veins rarely crosscut the Longarm Formation.

Zones of intense veining localize erosion of the granitic rocks to wave-cut benches. The zones vary from a few tens of meters to a kilometre in width. There are no bounding faults to these zones; "horses" of comparatively unveined rock grade into more intensely altered equivalents. The fracture-alteration zones likely reflect hydro-fracture of the granite and expulsion of hydrothermal fluids and signal the waning stages of plutonism. BIPS is cospatial with iron-copper skarns developed in the Upper Triassic Kunga Group limestone (e.g. Jedway, Jib deposits; Sutherland Brown, 1968). Hydrothermal alteration of the Kunga Group which fostered the skarns and which may account for high conodont colour alteration indices (Orchard, 1988) was coeval and cogenetic with the Late Jurassic BIPS.

Potassium-argon isotopic ages for BIPS hornblende range from 145-164 Ma (Young, 1981; Anderson and Reichenbach, 1989). The oldest Callovian to Oxfordian isotopic age (Anderson and Reichenbach, 1989) is consistent with the Bajocian to Early Cretaceous stratigraphic age for the suite and are indistinguishable from the range of K-Ar ages for SCPS.

TERTIARY KANO PLUTONIC SUITE (KPS)

Oligocene plutons of the Kano plutonic suite are scattered along the west and east coasts of Moresby and Graham islands and underlie the northern half of Langara Island (Fig. 1). Langara (13 km^2), Sialun Creek (2 km^2), Pivot Mountain (7 km^2), Sheila Lakes (<53 km^2), Kano (110 km^2), and Pocket Inlet (60 km^2) plutons are subcircular intrusions within the western belt of the suite. Pocket Inlet pluton has a flat roof and overall bell-jar shape. Southern Louise (4 km^2), Talunkwan-Tangil (5 km^2), Atli (3 km^2), Lyell-Faraday islands (20 km^2), and Carpenter Bay (12 km^2) plutons are irregular to northwest-trending stocks of eastern-belt KPS.

Except for the Carpenter Bay plutons, KPS eastern- and western-belt intrusions are associated with high total field aeromagnetic values (56 400-57 100 gammas) and steep positive anomalies (300-500 gammas relief; Geological Survey of Canada, 1987a-g). Specific gravity values for a small sampling of the suite have a median value of 2.55.

The suite is heterogeneous, fine to medium grained, equigranular to seriate and massive; miarolitic cavities occur in some of the more felsic intrusions. Some plutons are typically homogeneous (quartz) diorite (Pivot Mountain and Sheila Lake pluton), quartz monzodiorite (Langara Island pluton), quartz monzonite (Sialun Creek pluton), monzogranite or granite (Atli and southeastern Sedgwick Bay plutons; Fig. 2). Many of the eastern belt plutons (southern Louise, Talunkwan-Tangil, Lyell-Faraday islands and Carpenter Bay plutons) and Pocket Inlet pluton are important exceptions because they comprise bimodal (mafic-felsic or intermediate-felsic) compositions (Fig. 2). Mafic inclusions are absent or unimportant compared to xenolith-rich Late Jurassic suites. Fine to medium grained, seriate monzodiorite inclusions predominate.

Mafic mineralogy varies with pluton composition. Orthopyroxene and lesser clinopyroxene are important in the mafic plutons (e.g. Sheila Lake and Pivot Mountain). Hornblende, with or without biotite, is most abundant in intermediate compositions (e.g. Sialun Bay, Kano, southern Louise, Talunkwan-Tangil, Lyell-Faraday and Carpenter Bay plutons). Biotite predominates in monzogranite and granite intrusions (Pocket Inlet, Atli and parts of Lyell-Faraday islands plutons).

KPS crosscuts all Mesozoic units in the Queen Charlotte Islands (Sutherland Brown, 1968). Cretaceous-Tertiary, possibly pre-Masset Formation, intermediate and felsic flow, volcaniclastic and pyroclastic rocks are the youngest strata intruded by the suite.

Mafic or intermediate phases are intruded by felsic phases in bimodal plutons. North-trending interphase intrusive contacts in the Carpenter Bay and Lyell-Faraday islands plutons are coplanar with dykes which characterize the plutons. Pocket Inlet pluton provides a striking example of intrusive relations in bimodal plutons. Some of the host rock fragments caught up in the spectacular agmatites described by Sutherland Brown (1968) are equigranular, medium-grained gabbro.

Many of the KPS phases of intermediate composition contain porphyritic dyke equivalents. Carpenter Bay and Lyell-Faraday islands plutons provide the best example. North-trending, aphanitic and plagioclase-, hornblende-, biotite-, alkali-feldspar- and/or pyrite-phyric andesite (most common), dacite and trachyte (least common) dykes intrude and are intruded by equigranular and seriate plutonic phases. Hornblende from one hornblende porphyry andesite dyke of the Burnaby Island-Carpenter Bay swarm yielded a Middle Eocene K-Ar age (Anderson and Reichenbach, 1989). The Carpenter Bay and Lyell-Faraday islands plutons and dykes represent the barely unroofed roots of Tertiary volcano-plutonic complexes.

Isotopic ages for KPS and associated dykes, described in more detail by Anderson and Reichenbach (1989), range from 24-44 Ma. Coeval bimodal plutonism (e.g. Pocket Inlet pluton) and dyking (e.g. Carpenter Bay and Lyell-Faraday islands plutons) indicate an important period of Middle to Late Eocene extension which may herald opening of the Queen Charlotte basin.

Zircon fractions from northwestern members of KPS yield mostly concordant U-Pb isotopic ages which refine earlier K-Ar isotopic chronometry (Young, 1981) and define the south to north time-transgressive plutonism as three distinct plutonic episodes of decreasing periodicity: 40-44 Ma, 32 Ma and 27-28 Ma.

GEOCHEMISTRY

Geochemical compositions for 38 representative samples of some of the Mesozoic and Tertiary plutons and dykes are summarized in Figure 4. All three plutonic suites share an

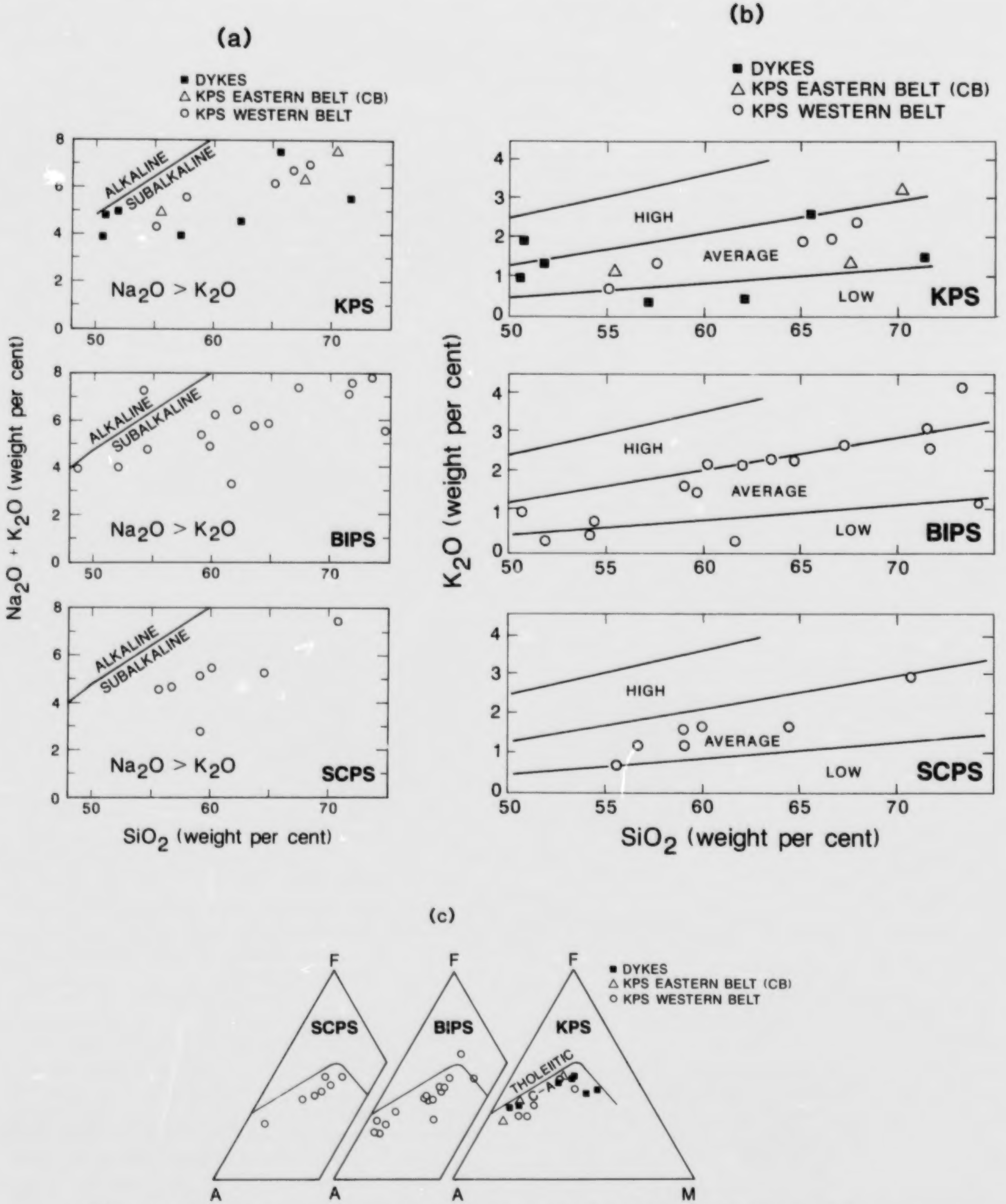
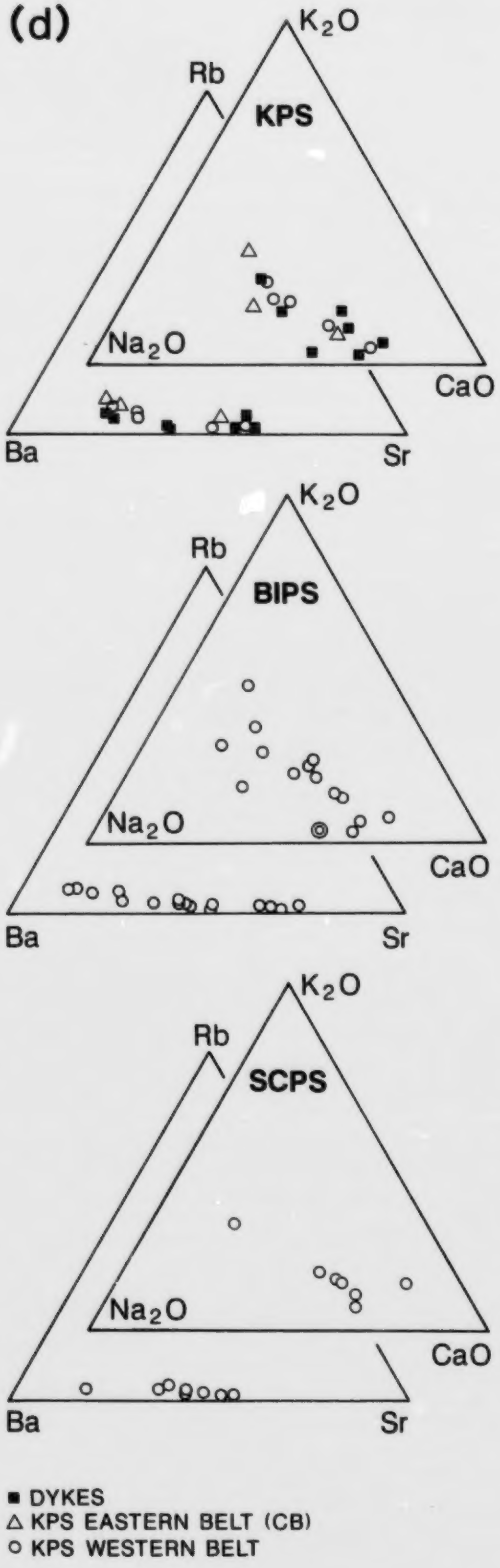
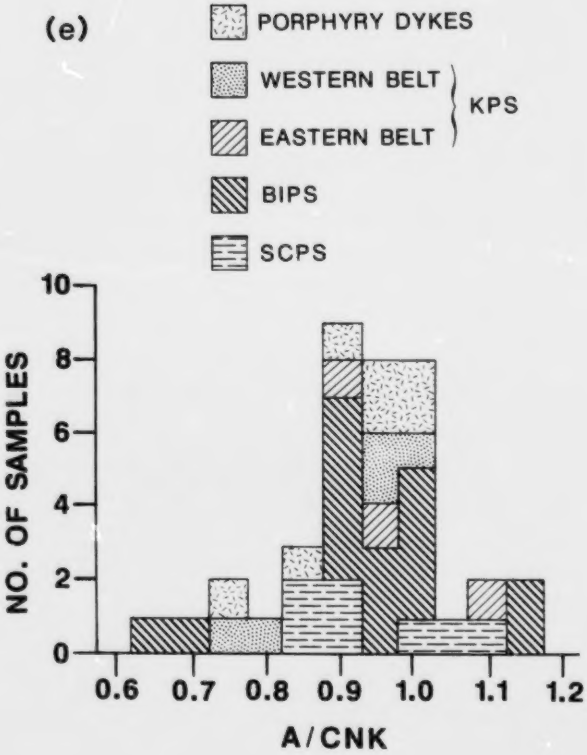


Figure 4. Geochemical variation amongst 1987 samples of Late Jurassic and Tertiary plutonic suites: San Christoval plutonic suite (SCPS), Burnaby Island plutonic suite (BIPS) and Kano plutonic suite (KPS). **a)** total alkali-silica variation (subalkaline-alkaline division after Irvine and Baragar (1971); Na_2O is greater than K_2O for all suites); **b)** K_2O-SiO_2 variation diagram (divisions after Peccerillo and Taylor, 1976); **c)** AFM ternary (calc-alkaline (C-A)-tholeiitic division after Irvine and Baragar (1971); **d)** Rb-Ba-Sr and inset K_2O-Na_2O-CaO ternary diagrams; and **e)** molar $Al_2O_3/(K_2O + Na_2O + CaO)$ (= A/CNK) histogram. Tertiary dykes and western-belt and eastern-belt KPS plutons are distinguished on the variation diagrams.





overall calc-alkaline, cafemic-rich, metaluminous, I-type composition. The plutons are of "average" potash composition (Peccerillo and Taylor, 1976) and are Na-rich compared to K. SCPS samples (except for the silicic sample of Luxana Bay leucosome) are compositionally restricted in accord with the suite's overall homogeneous composition. BIPS and KPS show more variety in geochemical composition as well as in outcrop. Mafic phases within BIPS and the Tertiary two-pyroxene diorite plutons are characterized by tholeiitic affinities in some diagrams. A compositional "gap" in geochemical variation within the largely bimodal KPS is mimicked by samples of compositionally similar, cospatial and coeval dykes.

SUMMARY

Late Jurassic and Tertiary plutonism on Queen Charlotte Islands account for 976 km^2 of the islands' area and about 140 million years of geological history. Each episode produced plutonic suites distinguished by plutonic and structural styles and stratigraphic and isotopic age. Thermal consequences of plutonism and associated dyking on maturation of Kunga Group reservoir rocks on southeastern Moresby Island were significant and locally compound where Jurassic and Tertiary plutonism overlap.

Late Jurassic (145-166 Ma (K-Ar)) plutons are divided into the San Christoval plutonic suite (SCPS) on the west coasts of Moresby and Graham islands and the Burnaby Island plutonic suite (BIPS) on the islands' east coast. SCPS is homogeneous, medium grained, foliated diorite and quartz diorite which contain common oblate mafic inclusions but few dykes (Sutherland Brown's (1968) "syntectonic" plutons). BIPS is heterogeneous (gabbro, diorite, quartz monzodiorite, quartz monzonite and trondhjemite (leucodiorite)), unfoliated and pervasively brittly fractured and veined. BIPS crosscuts Middle Jurassic and older strata and is nonconformably overlain by Lower Cretaceous Longarm Formation. Hydrothermal alteration of the Kunga Group must have also occurred between Middle Jurassic and Early Cretaceous and fostered copper-iron skarns in the host and endoskarn in the plutons.

Late Eocene to Oligocene (24-44 Ma (K-Ar and U-Pb)) Kano plutonic suite (KPS) occurs as two northwest-trending, sub-parallel belts of (quartz) monzodiorite and lesser diorite and granite stocks along parts of the west and east coasts of Graham and Moresby islands. Finer grain size, unfoliated and homogeneous character, small size, orthopyroxene, and miarolitic cavities distinguish KPS from Late Jurassic plutons. Tertiary, probable pre-Masset Formation, volcanic rocks are the youngest strata intruded by KPS. Isotopic ages for western belt plutons decrease from south to north. The oldest (Eocene) and most southerly KPS plutons are bimodal and/or are characterized by north-trending, intraplutonic porphyritic dykes and stocks (possible Masset feeders) and indicate extensional tectonics around 40-44 Ma.

Aphanitic and porphyritic dykes are important in all suites except the Jurassic San Christoval suite. Some eastern-belt plutons (Lyell-Faraday islands and Carpenter Bay plutons) represent barely unroofed roots of Tertiary volcano-plutonic complexes.

Reconnaissance geochemistry indicates overall calc-alkaline, average-K, metaluminous, cafemic-rich, and I-type affinities for all plutonic suites. Homogeneous composition for SCPS and crudely bimodal, and, in part, tholeiitic character for KPS are distinctive and corroborate their mineralogy. There is little correlation between composition and geographic position among members of the time-transgressive, western-belt Kano plutonic suite.

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A note on the geochronometry of Late Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia[1]

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Anderson, R.G. and Reichenbach, I., A note on the geochronometry of Late Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia; in Current Research, Part H. Geological Survey of Canada, Paper 89-1H, p. 105-112, 1989.

Abstract

K-Ar ages for hornblende from the San Cristoval plutonic suite (166 ± 3 Ma (2 σ)) and from the Burnaby Island plutonic suite (164 ± 3 Ma (2 σ)) are consistent with the suites' stratigraphic age (post-Pliensbachian, pre-Early Cretaceous).

Hornblende from a porphyritic andesite in the Carpenter Bay dyke swarm dated at 43.7 ± 1.1 Ma (2 σ). The K-Ar date suggests a minimum age for the Kano plutonic suite and a cooling age for part of the Carpenter Bay swarm. Coeval bimodal plutonism (e.g. Pocket Inlet pluton) and dyking indicate an important period of Late Eocene extension which may herald opening of the Queen Charlotte basin.

Zircons from northwestern members of the Kano Plutonic suite yield mostly concordant U-Pb ages which refine chronometry of south to north time-transgressive plutonism as three distinct episodes: 40-44 Ma, 32 Ma and 27-28 Ma.

Résumé

Des datations K-Ar de hornblende de la suite plutonique de San Cristoval (166 ± 3 Ma (2σ)) et de la suite plutonique de (164 ± 3 Ma (2σ)) concordent avec les datations stratigraphiques des suites (post-Pliensbachien, anté-début du Crétacé).

Le hornblende d'une andésite porphyrique du groupe de dykes de Carpenter Bay est âgée de 43,7 ± 1,1 Ma (2σ). La datation K-AR suggère un âge minimum pour la suite plutonique de Kano et un âge de refroidissement pour une partie du groupe de Carpenter Bay. Le plutonisme (p. ex. pluton du bras Pocket) bimodal et la formation de dykes contemporains indiquent une importante période d'extension à la fin de l'Éocène qui peut avoir annoncé l'ouverture du bassin de la Reine-Charlotte.

Les zircons des membres nord-ouest de la suite plutonique de Kano permettent des datations U-Pb principalement concordantes qui affinent la chronométrie du plutonisme transgressif en fonction du temps du nord au sud en trois épisodes distincts: 40 à 44 Ma, 32 Ma et 27 à 28 Ma.

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[1] Contribution to Frontier Program

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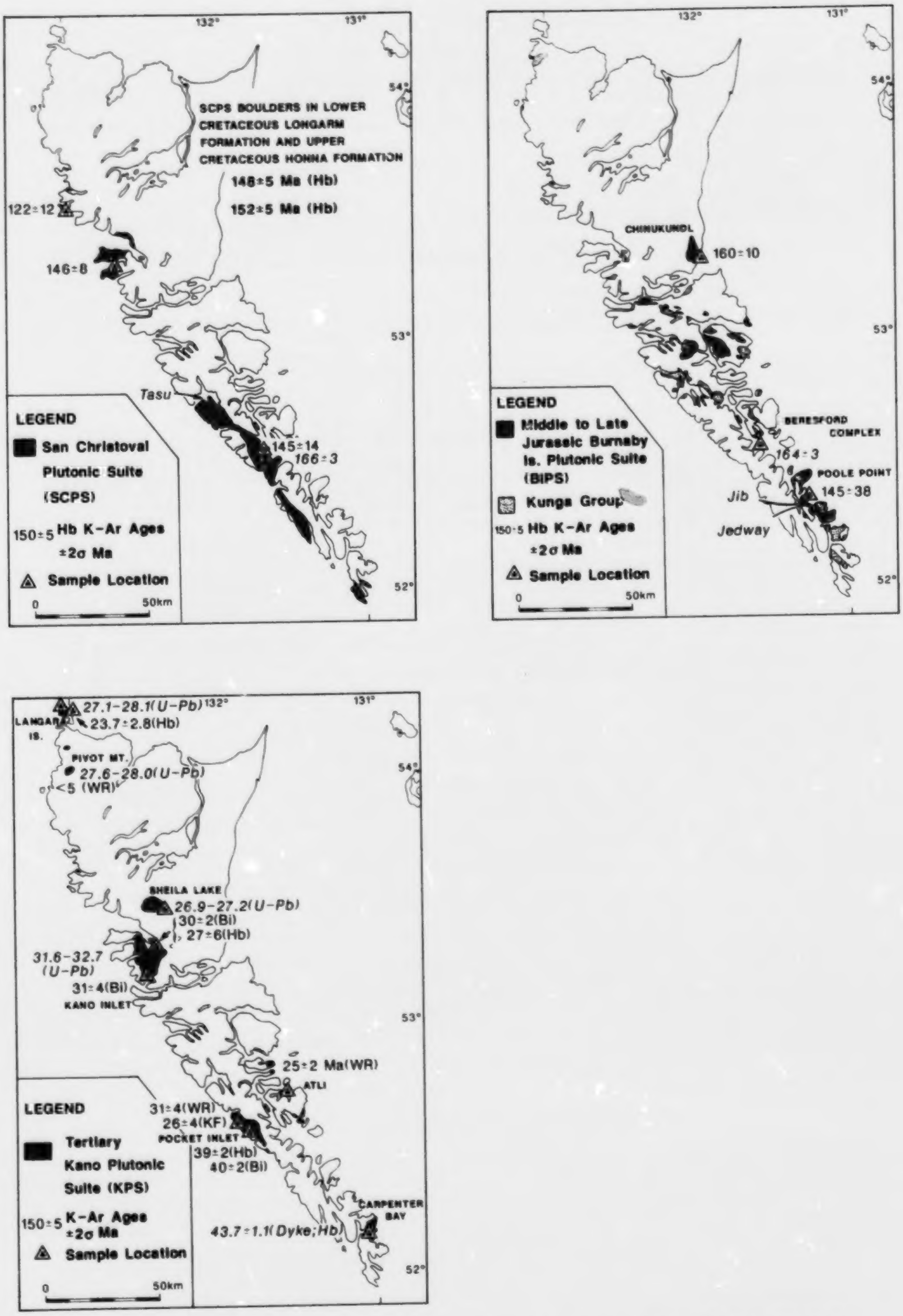
132°
131°
54°
53°
52°
SCPS BOULDERS IN LOWER CRETACEOUS LONGARM FORMATION AND UPPER CRETACEOUS HONNA FORMATION
148±5 Ma (Hb)
152±5 Ma (Hb)
122±12
146±8
Tasu
145±14
166±3
LEGEND
San Christoval Plutonic Suite (SCPS)
150±5 Hb K-Ar Ages ±2σ Ma
Sample Location
0
50km
CHINUKUNDL
160±10
BERESFORD COMPLEX
164±3
POOLE POINT
145±38
Jib
Jedway
LEGEND
Middle to Late Jurassic Burnaby Is. Plutonic Suite (BIPS)
Kunga Group
150±5 Hb K-Ar Ages ±2σ Ma
Sample Location
27.1–28.1(U–Pb)
23.7±2.8(Hb)
LANGARA IS.
PIVOT MT.
27.6–28.0(U–Pb)
<5 (WR)
SHEILA LAKE
26.9–27.2(U–Pb)
30±2(Bi)
27±6(Hb)
31.6–32.7 (U–Pb)
31±4(Bi)
KANO INLET
25±2 Ma(WR)
ATLI
31±4(WR)
26±4(KF)
POCKET INLET
39±2(Hb)
40±2(Bi)
CARPENTER BAY
43.7±1.1(Dyke;Hb)
LEGEND
Tertiary Kano Plutonic Suite (KPS)
150±5 K-Ar Ages ±2σ Ma
Sample Location

Figure 1. Distribution of Late Jurassic and Tertiary plutonic suites in Queen Charlotte Islands and isotopic ages. New K-Ar and U-Pb dates are shown in italic lettering. Sources for earlier determinations are given in text.

INTRODUCTION

Isotopic age is the fundamental criterion for inclusion of disparate plutons and their plutonic styles in the definition of a plutonic suite. In the Queen Charlotte Islands, a regional K-Ar isotopic age database has been available for some time (Young, 1981). However, the isotopic ages appeared to conflict with the plutonic framework established by Sutherland Brown (1968). Jurassic syntectonic plutons were shown to be coeval with post-tectonic plutons, formerly thought to be Cretaceous-Tertiary (Sutherland Brown, 1968; Young, 1981).

A program of regional U-Pb and detailed K-Ar isotopic dating is underway to complement new mapping of the granitic intrusions on the Queen Charlotte Islands to resolve this and other problems (Anderson, 1988a, b, c; Anderson and Greig, 1989). Initial K-Ar results for hornblende from Jurassic and Tertiary intrusions and U-Pb results for zircon from plutons on Graham Island are outlined in this paper.

Earlier and new isotopic ages fit with new data on the plutonic style and intrusive relations which define two Late Jurassic plutonic suites: the San Christoval (SCPS) and Burnaby Island (BIPS) plutonic suites. The Jurassic data are consistent with the stratigraphic age of the two suites (post-Pliensbachian, pre-Early Cretaceous) and indicate their contemporaneity.

K-Ar dates and concordant U-Pb isotopic ages refine chronometry of south to north time-transgressive Tertiary Kano plutonic suite (KPS) plutonism as three distinct plutonic pulses: 40-44 Ma, 32 Ma and 27-28 Ma. Dyking and bimodal plutonism were important in the earliest Tertiary plutonic episode and indicate a period of Late Eocene extension which may be related to early opening of the Queen Charlotte basin.

Ages for the plutonic suites are important in the evaluation of the thermal effects of granite intrusion and associated hydrothermal circulation in the overmaturation of possible reservoir host rocks such as the Upper Triassic Kunga Group (Orchard, 1988).

GEOLOGICAL SETTING

Late Jurassic and Tertiary plutonism on Queen Charlotte Islands account for 1000 km^2 of the land area and about 140 million years of geological history. Each plutonic episode produced granitoid rocks with distinctive plutonic and structural styles and stratigraphic and isotopic age.

Late Jurassic plutons are divided into the San Christoval plutonic suite (SCPS) on the west coasts of Moresby and Graham islands and the Burnaby Island plutonic suite (BIPS) on the islands' east coast (Fig. 1). SCPS is homogeneous, medium grained, foliated diorite and quartz diorite which contain common inclusions but few dykes. The foliated nature of mafic inclusions and local mineral foliation led to Sutherland Brown's (1968) "syntectonic" classification for the suite. Hornblende is distinctly prismatic and biotite is rare, texturally late and commonly chloritized. Pliensbachian and Upper Triassic Kunga Group rocks are the youngest strata intruded by SCPS.

BIPS is heterogeneous (gabbro, diorite, quartz monzodiorite, quartz monzonite and trondjhemite (leucodiorite)), unfoliated and pervasively brittly fractured and veined. Hornblende is subhedral and as abundant as biotite except in felsic phases where biotite predominates. The massive nature of the plutons suggested a "post-tectonic" affinity to Sutherland Brown (1968).

The BIPS crosscuts Middle Jurassic (Bajocian) and older strata and the suite is nonconformably overlain by Lower Cretaceous Longarm Formation (Anderson and Greig, 1989). The nonconformable contact with the Longarm Formation differs from intrusive contacts reported by Sutherland Brown (1968, p. 139) for the Burnaby pluton and explains the apparent discrepancy between his suggested Cretaceous-Tertiary age for these "post-tectonic" plutons and Young's (1981) Late Jurassic K-Ar data from the pluton. Hydrothermal alteration and veining of the plutons, most strikingly developed as copper-iron skarns (Anderson, 1988c), is more intense in the plutons than in the nonconformably overlying Longarm Formation. Overmaturation of possible pre-Late Jurassic source rocks cospatial with BIPS, such as the Kunga Group (Orchard, 1988), must have also occurred between Late Jurassic and Early Cretaceous time if hydrothermal fluids were the culprit.

Late Eocene to Oligocene (24-40 Ma) Kano plutonic suite (KPS) occurs as two northwest-trending, sub-parallel belts of (quartz) monzodiorite and lesser diorite and granite stocks along parts of the west and east coasts of Graham and Moresby islands. Finer grain size, unfoliated and homogeneous character, small size, orthopyroxene, and common miarolitic cavities distinguish KPS from Late Jurassic plutons. Tertiary, probable pre-Masset Formation, volcanic rocks are the youngest strata intruded by KPS. Isotopic ages for western belt plutons decrease from south to north. The oldest plutons in KPS are bimodal or are characterized by north-trending, intraplutonic porphyritic dykes and stocks (possible Masset feeders) and indicate extensional tectonics around 40 Ma.

Aphanitic and porphyritic dykes are an important part of magmatism associated with the plutonic suites (Souther, 1988; Souther and Bakker, 1988). All suites except the Jurassic San Christoval suite, have common (hornblende-) plagioclase phyric and aphanitic green andesite dykes. The north-trending Carpenter Bay dyke swarm is particularly striking in consistency of orientation, extent, and concordance of dyke geometry with intraphase contacts within Carpenter Bay plutons.

GEOCHRONOMETRY

Previous work

Geological Survey of Canada (Wanless et al., 1968, 1970, 1972) and University of British Columbia (Young, 1981; Yorath and Chase, 1981) geochronometry laboratories contributed to the early K-Ar isotopic age database (summarized in Fig. 1 and in Young, 1981). "Syntectonic" and some "post-tectonic" plutons (e.g. SCPS around Kano and Haswell inlets and the Chinikundl and Poole Point plutons of BIPS) were shown to be coeval and Late Jurassic (145-160 Ma age range; all ages consistent with decay constants of Steiger and Jäger, 1977). Hornblende-bearing quartz diorite (SCPS-equivalent?) fragments characterize Cretaceous coarse clastic sedimentary rocks and date within the same age range (148-152 Ma on hornblende; Yorath and Chase, 1981).

The western belt of known Tertiary "post-tectonic" plutons (Pocket Inlet, Kano, and Langara plutons) decrease in age from south (39-40 Ma) to north (about 24 Ma). Whole rock and alkali-feldspar K-Ar dates were younger than coexisting hornblende-biotite mineral pairs (e.g. 26 and 31 Ma dates for Pocket Inlet pluton alkali-feldspar or whole rock) or uninterpretable (e.g. < 5 Ma date for Pivot Mountain).

Analytical methods and data

Samples collected in 1987 by Anderson and C.J. Hickson are representative of: southern and central SCPS around Woodruff Bay and Haswell Bay-de la Beche Inlet; of southern, central and northern BIPS (Jedway, Burnaby Island, Lyell and Bischof islands and Cumshewa Head plutons); and of eastern-belt plutons and cogenetic dykes of KPS (Carpenter Bay, Collison Bay and Section Cove) and western-belt plutons of KPS (Kano, Sheila Lake, Pivot Mountain and Langara Island). Initial K-Ar results for hornblende are available for central SCPS, central BIPS, and a north-trending, Carpenter Bay hornblende-phyric andesite dyke (Table 1). U-Pb isotopic determinations for zircon from Kano, Sheila Lake, Pivot Mountain, and Langara Island plutons are reported here (Table 2).

Analytical techniques for K determinations and Ar analysis follow Roddick and Souther (1987). Zircon was dated by U-Pb methods using analytical procedures summarized by Parrish et al. (1987). Zircons from all KPS plutons are clear (rarely inclusion-bearing) and either prismatic or stubby and equant.

K-Ar results

Nearly identical K-Ar dates for SCPS (166 ± 3 Ma) and BIPS (164 ± 3 Ma) hornblendes are slightly older than earlier determinations (145-160 Ma) for the suites and emphasize the contemporaneity of the two suites. A latest Middle to earliest Late Jurassic (Callovian-Oxfordian) isotopic age for BIPS is consistent with its Bajocian to Early Cretaceous stratigraphic age.

The latest Middle Eocene isotopic age for hornblende from the Carpenter Bay porphyritic dyke (43.7 ± 1.1 Ma) is slightly older than but compares closely with K-Ar ages from the Pocket Inlet pluton (39-40 ± 2 Ma; Young, 1981). The northerly trends of the dykes are mimicked by orientation of interphase contacts in Carpenter Bay plutons which host the dykes. Similar extensional tectonic conditions apparently prevailed through pluton emplacement to the later dyking. Late Eocene (40-44 Ma) extension in southeastern Queen Charlotte Islands is reflected in bimodal plutonism in Pocket Inlet pluton (Anderson and Greig, 1989) and in widespread dyking (and probable coeval plutonism) in and south of Carpenter Bay.

Table 1. K-Ar data for hornblende from Late Jurassic plutons and a Tertiary dyke

Sample Number	G.S.C. Lab Number	Locality	K (wt. %)	Rad. ^{40}Ar ((10^{-7}) cc/g STP)	%Rad. ^{40}Ar	Age (±2 σ Ma[1]) (hornblende)
		BURNABY ISLAND-CARPENTER BAY DYKE SWARM				
AT-87-7-3	3980	Benjamin Point[2]	0.511	8.783	34.0	43.7 ± 1.1
		BURNABY ISLAND PLUTONIC SUITE (BIPS)				
AT-87-122-1	3977	Bischof Islands[3]	0.262	17.44	22.0	164 ± 3
		SAN CHRISTOVAL PLUTONIC SUITE (SCPS)				
AT-87-115-1	3979	Sac Bay[4]	0.521	35.23	38.0	166 ± 3

1. σ= standard error.
2. hornblende-plagioclase andesite dyke; UTM (zone 9) 5786550 N, 363100 E; 53°12′51″ N, 131°00′14″ W (NTS 103 B/3); peninsula south of Carpenter Bay, north of Benjamin Point, 2 km south of Langtry Isand at sea level.
3. biotite-hornblende quartz monzodiorite; UTM (zone 9) 5828400 N, 325925 E; 52°34′47″ N, 131°34′09″ W (NTS 103 B/12E); western coast of northernmost island of Bischof Islands, 1 km east of Richardson Point, 2.6 km southwest of Sedgwick Point at sea level.
4. biotite-hornblende diorite; UTM (zone 9) 5823375 N, 318650 E; 52°31′56″ N, 131°40′25″ W (NTS 103 B/12E); southeast end of Sac Bay, off de la Beche Inlet, 3.5 km west-southwest of de la Beche Island, 5.6 km southwest of Darwin Point at sea level.

U-Pb results

Eight of twelve fractions from the northwestern KPS plutons are concordant and have acceptably small errors. Discordance and/or large errors in $^{207}Pb/^{235}U$ ratio relate to fractions containing a predominance of inclusion-rich zircon fragments or fractions containing few zircons and having large common Pb blank values. The internal agreement of the concordant fractions from a particular pluton and with available K-Ar data (e.g. for Kano and Langara plutons) suggests that further work would not change the results appreciably.

Concordant fractions (Fig. 2) indicate two distinct plutonic pulses, 32 Ma and 27-28 Ma (quoted age is mean of $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages from the best two fractions and errors are 2σ): 32.2 ± 1.0 Ma (Kano pluton); 27.0 ± 0.3 Ma (Sheila Lake pluton); 27.9 ± 0.4 Ma (Pivot Mountain pluton); and 26.8 ± 0.4 Ma (Langara pluton). U-Pb dates are slightly older than available K-Ar dates for the same pluton. Distribution of the U-Pb dates confirms the south to north time-transgressive pattern defined by the K-Ar dates (Fig. 1) and emphasizes three distinct plutonic episodes of decreasing periodicity: 40-44 Ma, 32 Ma and 27-28 Ma. Coeval Langara, Pivot Mountain and Sheila

Table 2. U-Pb data for zircon in Tertiary plutons in Queen Charlotte Islands.

Mineral Fraction[1] size, appearance	Wt. (mg)	U (ppm)	Pb[2] (ppm)	$\frac{^{206}Pb}{^{204}Pb}$[3]	Pb_c[4] (pg)	^{208}Pb[2] (%)	$\frac{^{206}Pb}{^{238}U}$ (± 1 SEM (%))[5]	$\frac{^{207}Pb}{^{235}U}$ (± 1 SEM (%))[5]	$\frac{^{207}Pb}{^{206}Pb}$ (± 1 SEM (%))[5]	$\frac{^{206}Pb}{^{238}U}$ Age (Ma)	$\frac{^{207}Pb}{^{235}U}$ Age (Ma)	$\frac{^{207}Pb}{^{206}U}$ Age (Ma)[6] (± 1 SEM)
KANO PLUTON - SAMPLE AT-87-80-1[7]												
−105+74, abr clear, equant	0.011	390.1	2.0	90.9	23.9	12.9	0.0051 (0.410)	0.0321 (1.538)	0.0459 (1.366)	32.7	32.1	0.0 (+54.7/−0.0)
−105+74, abr. incl., prisms	0.0177	264.7	1.4	97.7	23.4	15.6	0.0050 (0.325)	0.0316 (1.302)	0.0454 (1.134)	32.5	31.6	0.0 (+19.7/−0.0)
+105, abr incl., equant	0.0077	501.7	2.7	83.2	24.5	16.1	0.0051 (0.467)	0.0304 (2.417)	0.0436 (2.140)	32.5	30.4	0.0 (± 0.0)
SHEILA LAKE PLUTON - SAMPLE CH-87-30-09[7]												
−149+105, abr clear, equant	0.0271	762.2	3.5	411.8	14.6	18.9	0.0042 (0.252)	0.0268 (0.511)	0.0466 (0.439)	26.9	26.9	26.6 (+20.9/−21.2)
−149+105, abr. clear, prisms	0.0191	605.02	2.8	319.8	11.2	17.3	0.0042 (0.116)	0.0272 (0.615)	0.0470 (0.563)	26.9	27.2	51.6 (+26.6/−27.1)
−105+74, abr clear, frags.	0.0163	684.2	3.1	63.8	64.9	17.2	0.0042 (0.937)	0.0254 (3.242)	0.0442 (2.699)	26.8	25.5	0.0 (+27.9/−0.0)
PIVOT MOUNTAIN - SAMPLE CH-87-56-10[7]												
abr., equant to stubby	0.0042	2321.8	12.2	164.8	20.4	25.5	0.0044 (0.327)	0.0279 (1.575)	0.0464 (1.427)	28.0	28.0	20.9 (+67.1/−20.9)
abr., prisms	0.0044	2229.9	11.5	274.1	11.5	24.2	0.0043 (0.135)	0.0276 (0.366)	0.0462 (0.294)	27.9	27.6	6.6 (+14.1/-6.6)
LANGARA ISLAND PLUTON - SAMPLE CH-87-56-6[7]												
−149+105, abr., incl., prisms	0.0125	341.1	1.5	125.2	13.8	12.3	0.0042 (0.410)	0.0281 (1.724)	0.0485 (1.546)	27.1	28.1	121.4 (+71.3/−74.5)
−149+105, abr., clear, equant	0.0185	212.2	0.99	107.8	15.7	16.0	0.0043 (0.319)	0.0286 (2.653)	0.0478 (2.494)	27.9	28.7	91.1 (+114.1/−91.1)
−105+74, abr., clear, prisms	0.0538	354.8	1.5	342.3	16.4	11.8	0.0042 (0.137)	0.0266 (0.430)	0.0464 (0.393)	26.7	26.6	17.5 (+18.8/−17.5)
−105+74, abr., clear, equant	0.0364	241.1	1.1	190.1	15.2	15.9	0.0041 (0.192)	0.0271 (0.801)	0.0474 (0.723)	26.7	27.1	67.9 (+34.0/−34.8)

1. Sizes (e.g. − 105 + 74) refer to range of zircon length aspect in microns. Abbreviations are: abr. = abraded; clear = very few inclusions or inclusion-free; equant = stubby, equant grains; frags. = crystal fragments; incl. = inclusions present in grains; prism = euhedral prismatic crystals.
2. radiogenic Pb; corrected for blank and common Pb.
3. measured ratio, corrected for spike and fractionation.
4. total common Pb in analysis corrected for spike and fractionation.
5. corrected for blank Pb and U, common Pb, errors quoted are 1 standard error of the mean (SEM) in per cent.
6. corrected for blank and common Pb, errors are 1 standard of the mean (SEM) in Ma.
7. Sample information:
   Kano pluton, sample AT-87-80-1: hornblende (clinopyroxene)-biotite quartz monzodiorite; UTM (zone 8) 5898850 N, 668550 E; 53°12′51″ N, 132°28′30″ W (NTS 103 F/1); northeast side of Dawson Inlet, 1 km from north end of inlet, 4 km north-northwest of Meadow Mountain, at sea level.
   Sheila Lake pluton, sample CH-87-30-09: clinopyroxene-orthopyroxene diorite; UTM (zone 8) 5929875 N, 667550 E; 53°29′35″ N, 132°28′28″ W (NTS 103 F/8); from quarry outcrop 1 km northwest of north end of Sheila Lake, 0.5 km south-southwest of south end of Pam Lake, 2 km southwest of island in Marie Lake; collected by C. Hickson.
   Pivot Mountain pluton, sample CH-87-56-10: clinopyroxene-orthopyroxene diorite; UTM (zone 8) 5986900 N, 630860 E; 54°07′57″ N, 133°00′10″ W (NTS 103 K/3E-K/6E); west flank of Pivot Mountain (1650′ elevation), 3.2 km southeast of mouth of Beresford Creek, 5.4 km east-northeast of mouth of Hanakoot Creek; collected by C. Hickson.
   Langara Island pluton, sample CH-87-56-6: hornblende-biotite quartz monzodiorite; UTM (zone 8) 6013750 N, 627250 E; 54°15′28″ N, 133°02′48″ W (NTS 103 K/3E-K/6E); northwest corner of Langara Island, near lighthouse, 0.75 km east-northeast from Langara Point, 4.5 km north of Rhodes Point; collected by C. Hickson.

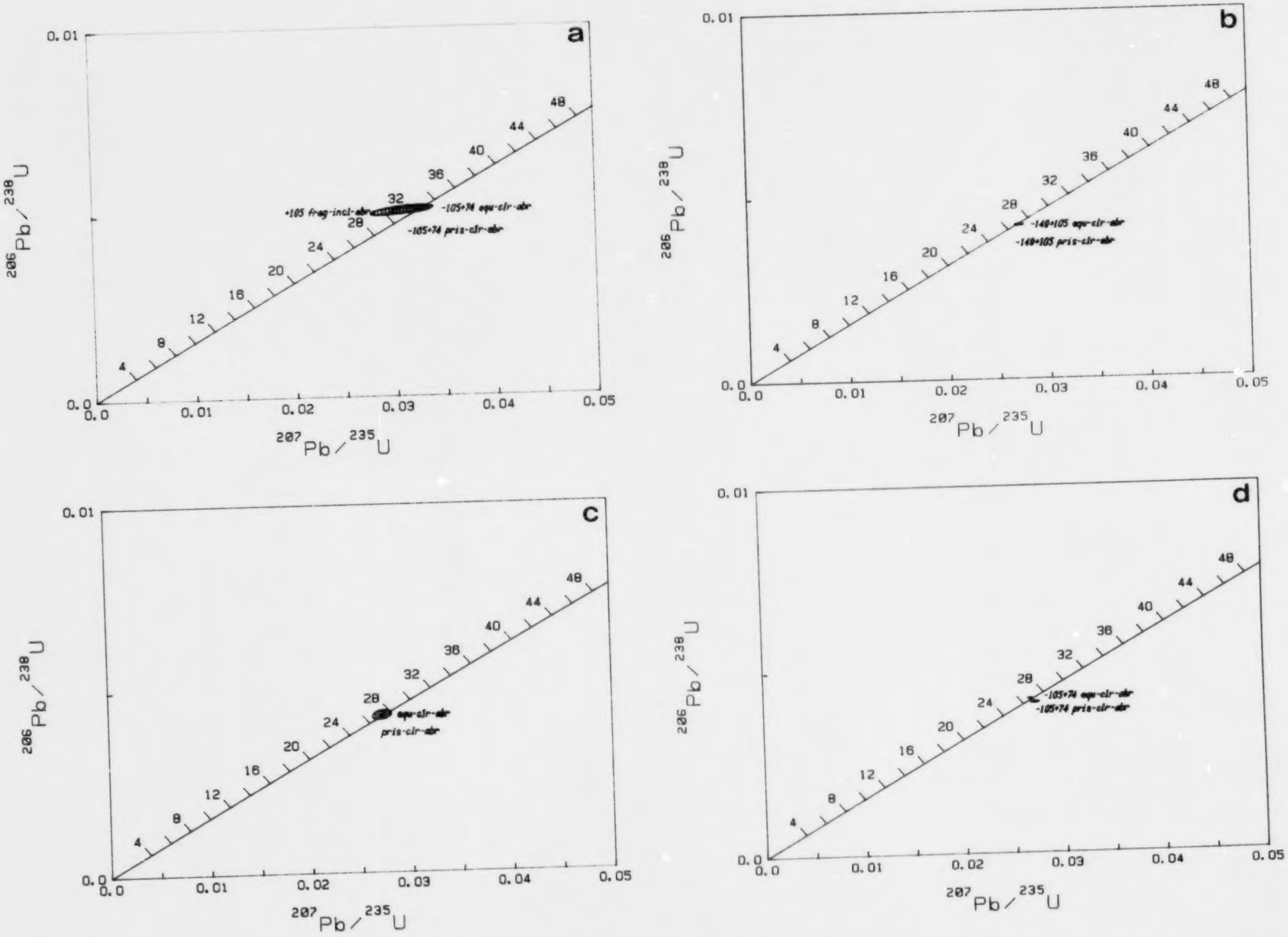

Figure 2. Uranium-lead concordia plots for zircons from: a) Kano pluton (sample AT-87-80-1), b) Sheila Lake pluton (sample CH-87-30-09), c) Pivot Mountain pluton (sample CH-87-56-10) and d) Langara pluton (sample CH-87-56-6). Zircon fractions with the least analytical error are plotted.

Lake plutons are not only cospatial with the most extensive outcropping of Masset Formation volcanic rocks on northwestern Graham Island, but the plutons' age compares closely with the Tertiary volcanic climax as defined by the median K-Ar age for the Masset Formation volcanic rocks (Fig. 3; Hickson, 1988).

SUMMARY

New K-Ar and U-Pb isotopic ages for members of the Late Jurassic San Christoval (SCPS) and Burnaby Island (BIPS) plutonic suites and Tertiary Kano plutonic suite (KPS) confirm determinations by earlier workers, refine chronometry of south to north time-transgressive plutonism, and indicate a Late Eocene period of extension.

Potassium-argon isotopic ages for hornblende from a SCPS sample (166 ± 3 Ma (2 σ)) and from a BIPS sample (164 ± 3 Ma (2 σ)) are slightly older than the age range of earlier K-Ar determinations (145-160 Ma), are consistent with stratigraphic age for the suites (post-Bajocian, pre-Early Cretaceous) and indicate contemporaneity of the two suites.

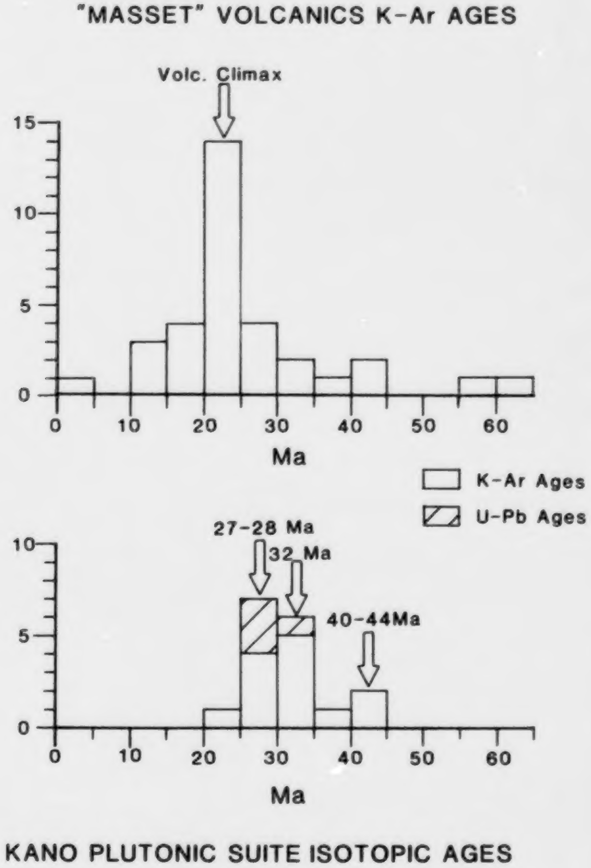

Figure 3. Histogram of K-Ar and U-Pb isotopic ages for Masset Formation volcanic rocks and Tertiary plutons in Queen Charlotte Islands. Three plutonic pulses at about 40-44 Ma, 32 Ma and 27-28 Ma are indicated as well as the median age for Masset Formation volcanic rocks (after Hickson, 1988).

Hornblende from a porphyritic andesite dyke member of the north-trending Carpenter Bay dyke swarm yielded a K-Ar isotopic age of 43.7 ± 1.1 Ma (2 σ). The age suggests a minimum age for eastern-belt plutons of KPS which appear to be coeval and cogenetic and provides a cooling age for at least part of the Carpenter Bay dyke swarm. Coeval bimodal plutonism (e.g., Pocket Inlet pluton) and dyking indicate an important period of Late Eocene extension which may herald opening of the Queen Charlotte basin to the east.

Zircon fractions from northwestern members of KPS yield mostly concordant U-Pb isotopic ages (average ages from south to north): 32.2 ± 1.0 Ma (Kano pluton); 27.0 ± 0.3 Ma (Sheila Lake pluton); 27.9 ± 0.4 Ma (Pivot Mountain pluton); and 26.8 ± 0.4 Ma (Langara pluton). The U-Pb isotopic ages are slightly older than or overlap earlier K-Ar mineral ages for the plutons and confirm three distinct, south to north, time-transgressive plutonic episodes of decreasing periodicity: 40-44 Ma, 32 Ma and 27-28 Ma.

ACKNOWLEDGMENTS

Cathie Hickson is thanked for collecting the samples from Langara, Pivot Mountain and Sheila Lake plutons as part of her regional mapping of the Masset Formation. The meticulous drafting of Brian Sawyer and Gena L'Esperance improved the clarity of the diagrams.

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Gravity measurements over the Burnaby Island pluton, Queen Charlotte Islands, British Columbia[1]

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Sweeney, J.F. and Seemann, D.A., Gravity measurements over the Burnaby Island pluton, Queen Charlotte Islands, British Columbia; ***in*** *Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 113-115, 1989.*

Abstract

Gravity measurements were taken at 62 stations along the shorelines of Burnaby and nearby islands. A local gravity anomaly of about -8 to -11 mGal indicates that the survey area is underlain by a felsic pluton with steep sides. The pluton is smaller than suggested by the strong magnetic anomaly high measured over the pluton.

Résumé

Des mesures gravimétriques ont été effectuées en 62 stations le long des rivages de l'île Burnaby et des îles avoisinantes. Une anomalie gravimétrique locale d'environ −8 à −11 mGal indique que la zone du levé repose sur un pluton felsique à côtés abrupts. Le pluton est plus petit que ne le suggère la valeur élevée mesurée pour l'anomalie à son emplacement.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

In June 1988, as part of the Queen Charlotte Islands, Frontier Geoscience Program, 62 gravity stations were acquired at about one kilometre intervals along the shorelines of Burnaby and nearby islands in the southeastern part of the archipelago (Fig. 1). The object was to determine if mapped granitic rocks in the vicinity produce a measurable gravity anomaly and, if so, to use the gravity data to assess the subsurface size and shape of the felsic bodies.

GRAVITY SURVEY

Gravity measurements were taken using Lacoste-Romberg gravimeter G009. Instrument readings were reduced to Bouguer anomalies using the International Gravity Standardization Network 1971 and the Geodetic Reference System 1967. A standard density of 2.67 g/cm^3 was used in the Bouguer correction.

Horizontal coordinates of gravity stations were determined from 1:50 000 NTS maps; the northing and easting co-ordinates of each station were scaled off with a template. Locations are estimated to be accurate to within 25 m.

Vertical co-ordinates were derived using a hand-held AIR altimeter continuously referenced to sea level. With tide tables provided by the Canadian Hydrographic Service, tidal corrections were applied to reduce the raw elevations to mean sea level. The accuracy of this method is thought to be within a few metres.

Regional terrain effects were removed from Bouguer values using the one kilometre digital elevation grid and computational routines available from the National Gravity Data Centre, Geological Survey of Canada, Ottawa. Local terrain effects, within a few kilometres of selected stations, have been determined at the Pacific Geoscience Centre using elevation data gridded at 125 to 500 m. The local correction, not reflected on the preliminary gravity map (Fig. 1), is everywhere less than 2 mGal.

GRAVITY FIELD

The regional gravity field becomes steadily more positive to the west across Hecate Strait and culminates in a linear high of up to 80 mGal along the western rim of the Queen Charlotte Islands (Fig. 1). A local gravity anomaly low, defined by the June 1988 survey, is present along the east

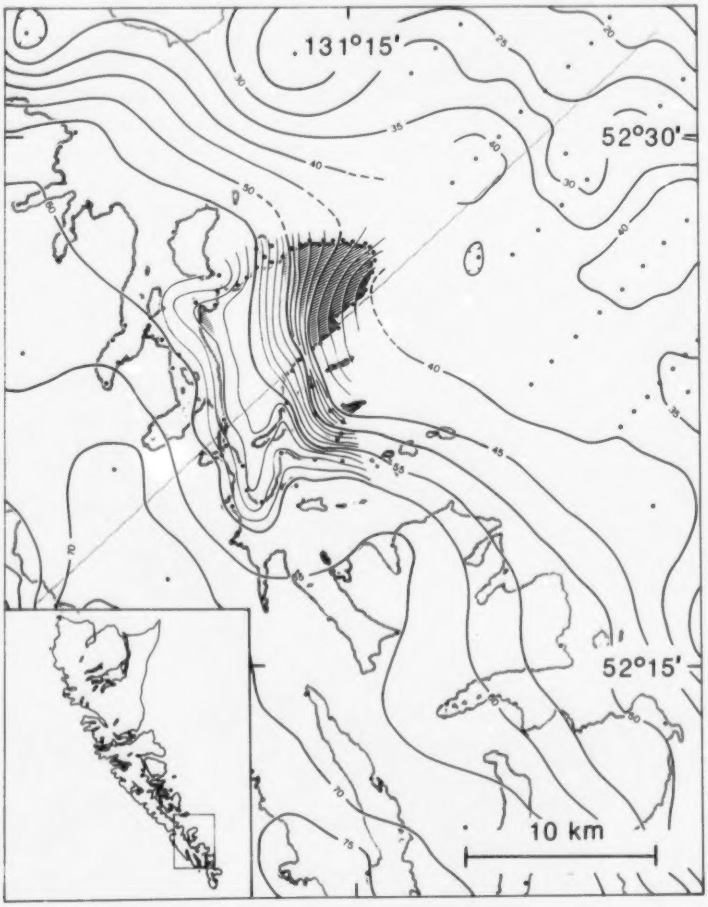

Figure 1. Gravity map of Burnaby Island area; Bouguer anomaly on land, Free air anomaly offshore. Gravity station distribution indicated by dots. Contour interval 5 mGal with 1 mGal contours over granitic exposures (shaded). Figure 2 profile indicated.

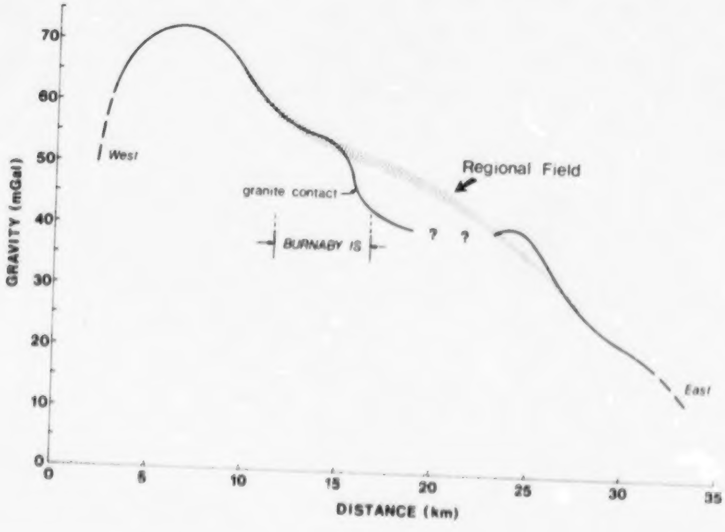

Figure 2. Gravity anomaly profile across Burnaby Island. Shorelines and pluton contact indicated. Preliminary regional anomaly field over the granite is shown. Profile location given on Figure 1.

side of the Burnaby Island group (Fig. 1, 2). The low lies over scattered granitic exposures and indicates that the felsic units are part of a large, mostly submarine pluton that is about 6 km wide, east to west, and about 12 km long, north to south (Fig. 1).

The gravity anomaly associated with the pluton has an amplitude of about -8 to -11 mGal (Fig. 2) suggesting that the body could be 3 or more kilometres thick. The position of the maximum gradient of the gravity anomaly relative to the pluton surface contacts (Fig. 2) suggests that, where exposed, the granite has steep to vertical sides.

The gravity study also shows the felsic body to be much smaller in area than the strong magnetic anomaly high measured over the pluton and areas to its south and east (Currie and Teskey, 1988). Hence, the magnetic high is probably unrelated to the emplacement of the granite. The magnetic signature may have been created by later structural deformation that produced extensive fracture and alteration zones within the plutonic suite and nearby host rocks (Anderson, 1988).

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Dyke swarms in the Queen Charlotte Islands, British Columbia[1]

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Souther, J.G., Dyke swarms in the Queen Charlotte Islands, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 117-120, 1989

Abstract

Dykes in the Queen Charlotte Islands display systematic regional variations in orientation and chemical composition. Those in the southern Moresby archipelago are relatively calcic and occur in north-trending swarms whereas those in northern Moresby and southern Graham islands have a more easterly trend and are relatively alkaline. The zone between these two domains is believed to define the trace of a boundary between discrete crustal blocks.

North-trending en echelon dyke swarms in the southern domain cut Cretaceous sediments and are probably mostly Tertiary. They are flanked on the southwest by a large dyke-free terrane, the south Moresby stable block. The geometric relationship is consistent with extension and dyke emplacement related to dextral movement between the south Moresby stable block and the western margin of Queen Charlotte Basin.

Résumé

Des dykes, dans les îles de la Reine-Charlotte, présentent des variations régionales systématiques d'orientation et de composition chimique. Ceux dans le sud de l'archipel Moresby sont relativement calciques et se présentent sous forme d'essaims de direction nord, alors que ceux dans le nord de l'archipel et le sud de l'île Graham sont orientés plus vers l'est et sont relativement alcalins. On pense que la zone située entre ces deux domaines définit la trace d'une limite entre des blocs crustaux distincts.

Des essaims de dykes en échelon, de direction nord, situés dans le domaine sud, traversent des sédiments crétacés et sont probablement, pour la plupart, d'âge tertiaire. Au sud-ouest, ces dykes sont flanqués d'un grand terrain exempt de dykes: le bloc stable sud de Moresby. La relation géométrique concorde avec la distension et l'intrusion des dykes associées au mouvement dextre qui existe entre le bloc stable sud de Moresby et la bordure ouest du bassin de la Reine-Charlotte.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

A study of dyke distribution in the Queen Charlotte Islands was begun in 1987 as part of a two-year FGP program to assess the petroleum potential of Queen Charlotte Basin. The study was designed to address two problems that bear directly on this objective:

1. The tectonic implications of dyke swarms and their relationship to basin evolution.
2. The effect of igneous heat on thermal maturation of hydrocarbons.

A preliminary account of 1987 field results (Souther, 1988) was followed by publication of petrographic and chemical data from the 1987 collections (Souther and Bakker, 1988). In 1988 two months were spent collecting additional field data on dykes along the coastlines of south Moresby and adjacent islands. This report gives a brief summary of the petrographic and chemical data, some highlights of the 1988 fieldwork, and a preliminary interpretation.

HIGHLIGHTS OF 1988 FIELDWORK

About 1000 station were occupied along the coastlines of south Moresby and adjacent islands. In general the new structural data confirm and add statistical weight to the locations and trends of dyke swarms sampled during the 1987 reconnaissance (Souther, 1988; Souther and Bakker, 1988). However, many dykes in the Carpenter Bay swarm, which was previously thought to comprise Jurassic (Yakoun) feeders (Souther, 1988), were found to cut Cretaceous (Longarm) sediments and are therefore probably Tertiary. This is consistent with a date of 43.7 ± 1.1 Ma reported by Anderson and Reichenbach (1989) on hornblende from a Carpenter Bay dyke.

New data on dyke distribution in the south Moresby archipelago define a series of north-trending, en echelon swarms, referred to informally as the Carpenter Bay, Skincuttle, Burnaby Island, and Lyell Island swarms (Fig. 1). The dyke swarms do not extend south into south-central Moresby Island, a region underlain mostly by Karmutsen volcanics and Mesozoic plutons of the San Christoval plutonic suite (Anderson, 1988). This large dyke-free area, the south Moresby stable block, appears to be part of a relatively competent northwesterly trending terrane which bounds the southeastern side of an extensional zone defined by the dyke swarms. The geometric relationship suggests that east-west extension, expressed by the dykes, may be related to dextral movement of the south Moresby stable block relative to Queen Charlotte Basin (Fig. 1). At present there is no way to estimate how far the dyke swarms extend north into Hecate Strait and hence what thermal effect that may have had on strata in the offshore part of the basin. However, data from both conodont colour alteration (Orchard, 1988) and from vitrinite reflectance studies (Vellutini, 1988) show an easterly increase in the time-temperature index across the southern Moresby archipelago. This suggests that igneous heat from the emplacement of Tertiary dyke swarms may have had a significant effect on thermal maturation of hydrocarbon-bearing rocks east of the south Moresby stable block.

A large subvolcanic complex on eastern Lyell Island (Fig. 2) comprises northerly trending andesite dykes and sheeted dyke swarms associated with a multiphase pluton of aphyric to moderately feldspar- and/or hornblende-phyric andesite. The andesite is associated with, and may be comagmatic with seriate monzodiorite (Anderson and Greig, 1989). The intrusive complex, which is similar in lithology, size, and structure to parts of the Carpenter Bay swarm, is flanked by and, appears to cut, proximal breccias and flows of Masset volcanics. Locally the intrusive andesite cuts and includes pendants of Mesozoic shale (Kunga or Sandilands ?). It seems likely that the Lyell Island and Carpenter Bay complexes are at least partly coeval, and that both are manifestations of east-west Tertiary extension associated with early Masset volcanism and high level plutonism along the western side of Queen Charlotte Basin.

PETROGRAPHY AND CHEMISTRY

Petrographic examination of dyke samples (Souther and Bakker, 1988) revealed a broad spectrum of compositions ranging from rhyolite to basalt. The majority of dykes (50%) are andesitic. Basalt comprises 35% of the dykes sampled whereas rhyolite and dacite together form only 15%. More than 75% of the dykes are aphyric and the porphyritic varieties commonly contain only a few percent of small plagioclase and/or hornblende phenocrysts. Most thin sections examined contain secondary chlorite plus varying amounts of calcite, biotite and leucoxene. Despite careful study of more than 80 thin sections no consistent petrographic criteria were found that could be used to discriminate between dykes of different ages or from different swarms.

Twenty-two chemical analyses of randomly selected dyke samples confirm the wide range of compositions indicated by petrography. Silica values range from 48 to 76% and all but two of the analyzed samples are quartz normative (Souther and Bakker, 1988). The chemical data fall into two groups which plot in overlapping fields on the AFM and Ab-An-Or diagrams (Fig. 3). Group 1, which comprises data from predominantly north-trending dykes on southern Moresby and adjacent islands, is significantly less alkaline and higher in Fe than group 2 which includes data from predominantly east- to northeast- trending dykes on northern Moresby, Louise and southern Graham islands. Differences between the two chemical regimes may reflect differences in the chemistry of source regions in adjacent

Figure 1. Index map showing the locations and average trends of the principal dyke swarms, Kunga Group sediments, and the domain boundary between the two chemical regimes plotted in Figure 3.

Figure 2. Sketch map showing the approximate extent of the Lyell Island igneous complex.

Figure 3. AFM and Ab-An-Or plots of 22 analyzed dyke samples. Analyses in group 1 are from dykes north of the boundary shown in Figure 1 whereas those in group 2 are from dykes south of the boundary.

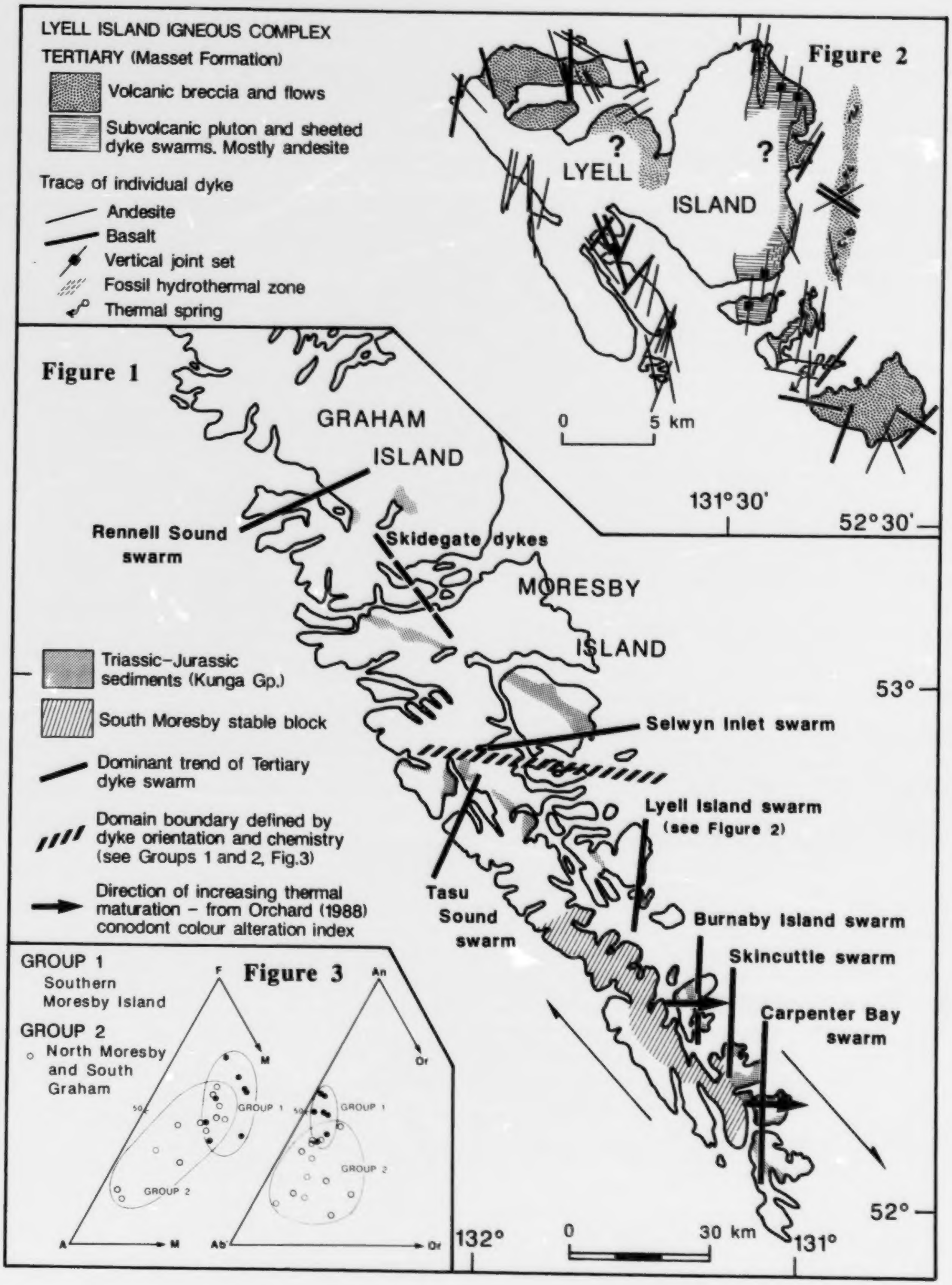
Figure 2
LYELL ISLAND IGNEOUS COMPLEX
TERTIARY (Masset Formation)
Volcanic breccia and flows
Subvolcanic pluton and sheeted dyke swarms. Mostly andesite
Trace of individual dyke
Andesite
Basalt
Vertical joint set
Fossil hydrothermal zone
Thermal spring
?
LYELL
?
ISLAND
0
5 km
131°30'
52°30'
Figure 1
GRAHAM
ISLAND
Rennell Sound swarm
Skidegate dykes
MORESBY
ISLAND
Triassic–Jurassic sediments (Kunga Gp.)
South Moresby stable block
Dominant trend of Tertiary dyke swarm
Domain boundary defined by dyke orientation and chemistry (see Groups 1 and 2, Fig.3)
Direction of increasing thermal maturation – from Orchard (1988) conodont colour alteration index
Selwyn Inlet swarm
Lyell Island swarm (see Figure 2)
Tasu Sound swarm
Burnaby Island swarm
Skincuttle swarm
Carpenter Bay swarm
53°
52°
132°
131°
0
30 km
Figure 3
GROUP 1
Southern Moresby Island
GROUP 2
North Moresby and South Graham
F
M
A
M
50
GROUP 1
GROUP 2
An
Or
Ab
Or
50
GROUP 1
GROUP 2

crustal blocks. The boundary zone as defined by dyke orientation and chemistry corresponds approximately with the southern margin of the Rennell Sound fold belt (Thompson, 1988).

TECTONIC SIGNIFICANCE AND THERMAL IMPACT

Dyke swarms in the Queen Charlotte Islands are believed to define zones of crustal weakness which, during Tertiary and possibly earlier time, have been the locus of repeated episodes of extension and igneous intrusion. The recognition of discrete swarms, several having different orientations, suggests a complex tectonic environment involving the interaction of terranes as small as 50 to 100 km across. The south Moresby stable block may be part of one such terrane, and the domain boundary south of the Rennell Sound fold belt (Fig. 1) is probably the boundary between discrete relatively rigid crustal blocks. The geometry of north-trending, en echelon dyke swarms in the south Moresby archipelago is consistent with a regime of east-west extension coupled to dextral transcurrent movement on northwesterly-trending faults.

Although most of the dykes are related to Masset (Tertiary) volcanism, many are believed to be older. Crosscutting relationships, and variations in the degree of deformation and alteration all point to episodic emplacement which may include dyke intrusion associated with volcanic rocks as old as the Middle Jurassic Yakoun Formation. Some of the fundamental structures that controlled dyke emplacement may be even older. A crude correlation between dyke swarms and the outcrop distribution of Upper Triassic and Lower Jurassic sediments (Fig. 1) suggests that both basin subsidence and later igneous activity may be manifestations of crustal weakness and extension on long-lived, deep crustal structures.

The impact of dyke emplacement on the thermal history of Queen Charlotte Basin is being investigated (Jessop and Souther, in prep.). Until the 1988 data are compiled and further modelling is done, it is possible to give only a subjective estimate of the effect of igneous intrusion on the thermal history of the basin. However, the empirical evidence from both conodont colour alteration index (Orchard, 1988) and vitrinite reflectance (Vellutini, 1988) suggests a strong correlation between the level of organic maturation and proximity to dyke swarms. Clearly any possible source or reservoir rocks within the major dyke swarms must have been raised to temperatures beyond the oil window. Although over-maturation due to conducted or hydrothermally transferred igneous heat may have been confined to rocks proximal to dyke swarms and associated plutons, the ubiquitous presence of chlorite suggests that dyke intrusion was accompanied or followed by regional metamorphism that may have affected a much larger area.

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Note on the thermal structure of Queen Charlotte Basin, British Columbia[1]

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Lewis, T.J., Bentkowski, W.H., Bone, M., and Wright, J.A., Note on the thermal structure of Queen Charlotte Basin, British Columbia; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 121-125, 1989.

Abstract

Preliminary results indicate low heat flux (50 mW m^{-2}) on the western margin of Queen Charlotte Basin and higher heat flux (75 mW m^{-2}) on the eastern margin. The lower values on the western margin are probably caused by present, oblique subduction. The heat generation is generally low within the basin and on its margins. Under the eastern margin, crustal temperatures are higher than those under the western margin of the basin. Marine techniques were used to measure the heat flux within the shallow sediments beneath Queen Charlotte Sound. However, results may reflect processes such as erosion and/or dewatering occurring at present within these sediments.

Résumé

Des résultats préliminaires indiquent un faible flux thermique (50 mW m^{-2}) à la marge occidentale du bassin de la Reine-Charlotte et un flux plus élevé (75 mW m^{-2}) à la marge orientale. Les valeurs plus faibles à marge occidentale sont probablement causées par la subduction oblique. Le flux thermique est généralement faible à l'intérieur du bassin comme à ses marges. Sous la marge orientale, les températures de la croûte sont plus élevées que celles relevées sous la marge occidentale du basssin. Des méthodes marines ont été utilisées pour mesurer les flux thermiques dans les sédiments peu profonds sous le détroit de la Reine-Charlotte. Toutefois, les résultats peuvent refléter des processus comme l'érosion ou l'assèchement, ou les deux qui agiraient actuellement dans ces sédiments.

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INTRODUCTION

Crustal temperatures within a basin are affected at any time by the thermal properties of the basin sediments; the heat flux from beneath the basin; the hydrological regime within the basin; magmatic intrusions; and the history of sedimentation, burial and erosion. At least three of these are directly governed by the tectonic history. Yorath and Hyndman (1983) calculated the paleo-heat flux and subsidence for the eight offshore wells in Queen Charlotte Sound and Hecate Strait using the recorded bottom hole temperatures (BHTs) and vitrinite reflection measurements on core samples. They suggested that the basin formed during an initial rifting event, followed by oblique subduction that continued up to the present. The present offshelf heat flux from Hyndman et al. (1982) (see Fig. 1) reflects the presence of the nearby spreading centre. Saas et al. (1985) have measured heat flux at nearby sites in southeastern Alaska. The objective of this study is to add to the meager geothermal data base in order to improve the modelling of the present and past thermal structure of the basin, and to compare the thermal states with those predicted by various tectonic models.

The thermal conductivity and heat production of the sediment matrix are being measured on cuttings from wells. The present thermal regime is being determined by measuring heat flux within the basin using wells and marine probe measurements and, on the margins of the basin, mineral exploration boreholes. The heat generation of the magmatic rocks surrounding the basin is also being measured. With the measured thermal parameters and the present state of the basin, past temperatures will be calculated. The following is an incomplete picture, because not all measurements and analyses are complete.

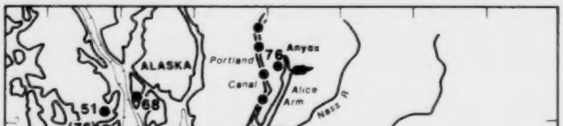

Figure 1. Site location map showing the measured heat flux in mW m^{-2}.

HEAT FLUX

The heat flux was determined using marine methods in the soft sediments beneath Queen Charlotte Sound and measurements associated with wells which have penetrated the sediments. At present, BHTs are being re-analyzed from the eight offshore wells and the thermal conductivity is being measured from representative cuttings from all the wells. The amount of coal in the sections will lower the thermal conductivity values from those used by Yorath and Hyndman (1983).

The use of marine methods to measure the heat flux on this shelf at water depths of less than 800 m involves the removal of the effects of large variations in bottom water temperatures (BWTs). To help mitigate these effects, heavy, 11-m long probes were used to obtain greater sediment penetration, because the effects decrease with depth. In general, the softest ponds of sediment on the shelf are more difficult to penetrate than those in the coastal inlets, and most deployments reached a sediment depth of only 7 m. Three cruises were made to acquire sets of data at individual sites and to recover instruments recording the variation of BWT between the cruises. Poor weather during the third cruise in May 1988 hampered the acquisition of data. Some data were obtained, but the mechanical parts of three 11-m probes were irreparably damaged. Although the analyses are not all complete, the first result, for Moresby Trough, is shown in Figure 1.

The measurement of heat flux from 24 mineral exploration boreholes and two geothermal resource evaluation boreholes at five sites on land is complete, but thermal conductivity measurements have not yet made for another site on Porcher Island (Figs. 2-5). The temperature logs, as a function of thermal depth, and the thermal conductivities are given. Only one of these sites with a single borehole (Anyox) appears to have a purely conductive gradient. Descriptions and discussions of methods and the effects of water flows in this type of topography are given in Lewis et al. (in press). A brief explanation of the interpretation necessary to arrive at the given heat flux for each site follows.

Denny Island (site 315): The heat flux from two boreholes differs, and the 74 mW m^{-2} from the deeper one is accepted. The temperatures are more likely to be disturbed for the shallower hole, which was drilled into a quartz-feldspar porphyry breccia having a higher heat generation than the leucocratic miarolitic granite which the deeper hole penetrated.

Anyox (site 356): The thermal conductivity varies from 2.25 to 7.08 W m^{-1} K^{-1} (Fig. 2), depending on the presence or absence of finely disseminated mineralization; dipping mineralized lenses or mineralized zones probably cause refraction. A topographic correction was made for this ridge site, and the average heat flux from 80 to 292 m depth is 75.5 mW m^{-2}.

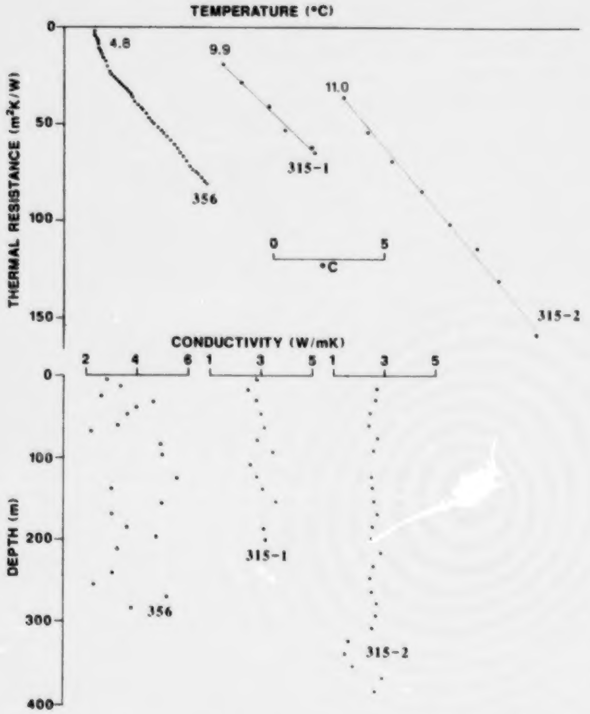

Figure 2. Bullard plot of relative temperature vs thermal resistance, and thermal conductivity as a function of depth for Denny Island (series 315) and Anyox (series 356). The most shallow absolute temperature for each hole is given.

Banks Island (site 357): Heat flux values from the 12 holes logged varies from 51 to 88 mW m^{-2}. Water flows, inferred from the non-linear temperature logs in the three shallow holes with the largest variations in heat flux, are not unexpected because the local geology includes limestone. Excluding these three results, the average heat flux measured in the other boreholes is 73.9 mW m^{-2}, and five of the individual borehole heat flux results are within 3 mW m^{-2} of this value. As this is a low area and all collar elevations are between 10 and 33 m ASL, this area is subject to climatic correction due to relative changes in sea level.

Cinola (site 368): The Cinola property is located on a topographic high, the Specogna fault separating it from low-lying Haida Formation shale and silicified shale to the northwest. The thermal data indicate water flow from the topographic high to the lower levels on the northwest. A concave-downward temperature log and the relatively higher surface intercept temperatures of two shallow boreholes in the valley (-25 and -26) indicate water flowing with an upward component (Fig. 4). The temperature logs of two boreholes near the cliff where the adit is located (-23 and -27) are dramatically affected by water flow. Other holes back from the cliff are less affected by water flow, and the best heat flux for each well is considered to be the average heat flux over the longest depth interval. The average value from these holes, 46.0 mW m^{-2}, is the best value, although it is a minimum value since water is flowing downward within the region used. The large variation in thermal conductivities is attributed to the varying degree of silicification of the rock.

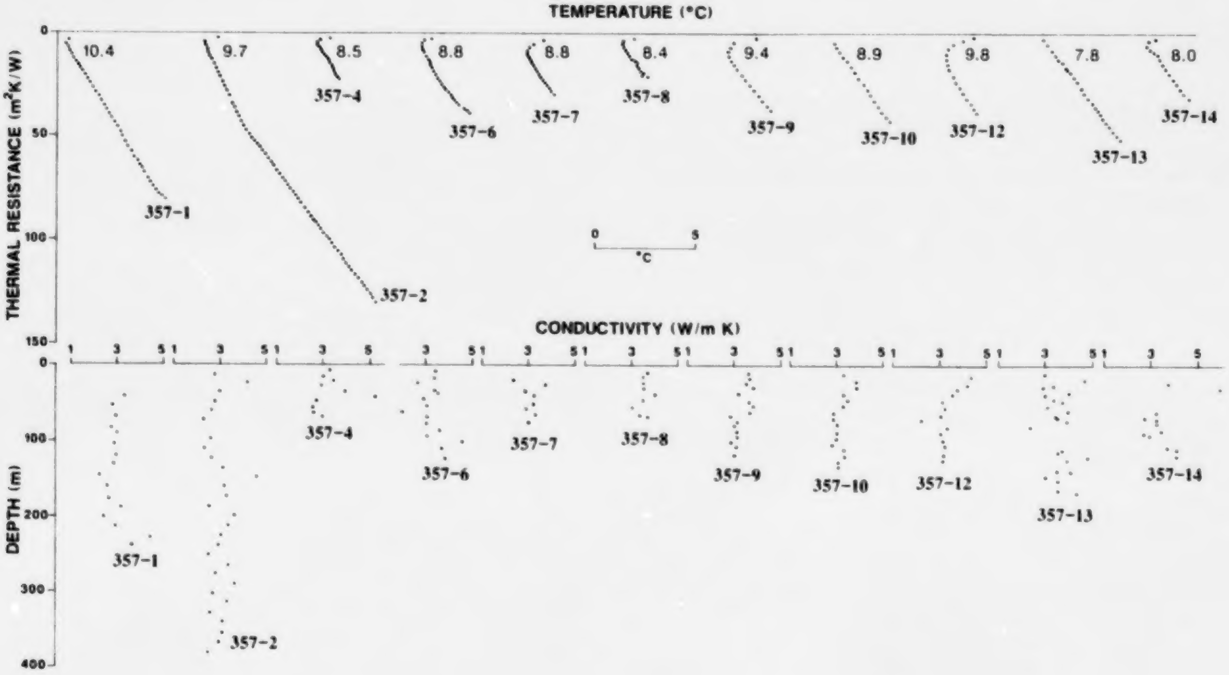

Figure 3. Plots as in Figure 2 for Banks Island (series 357).

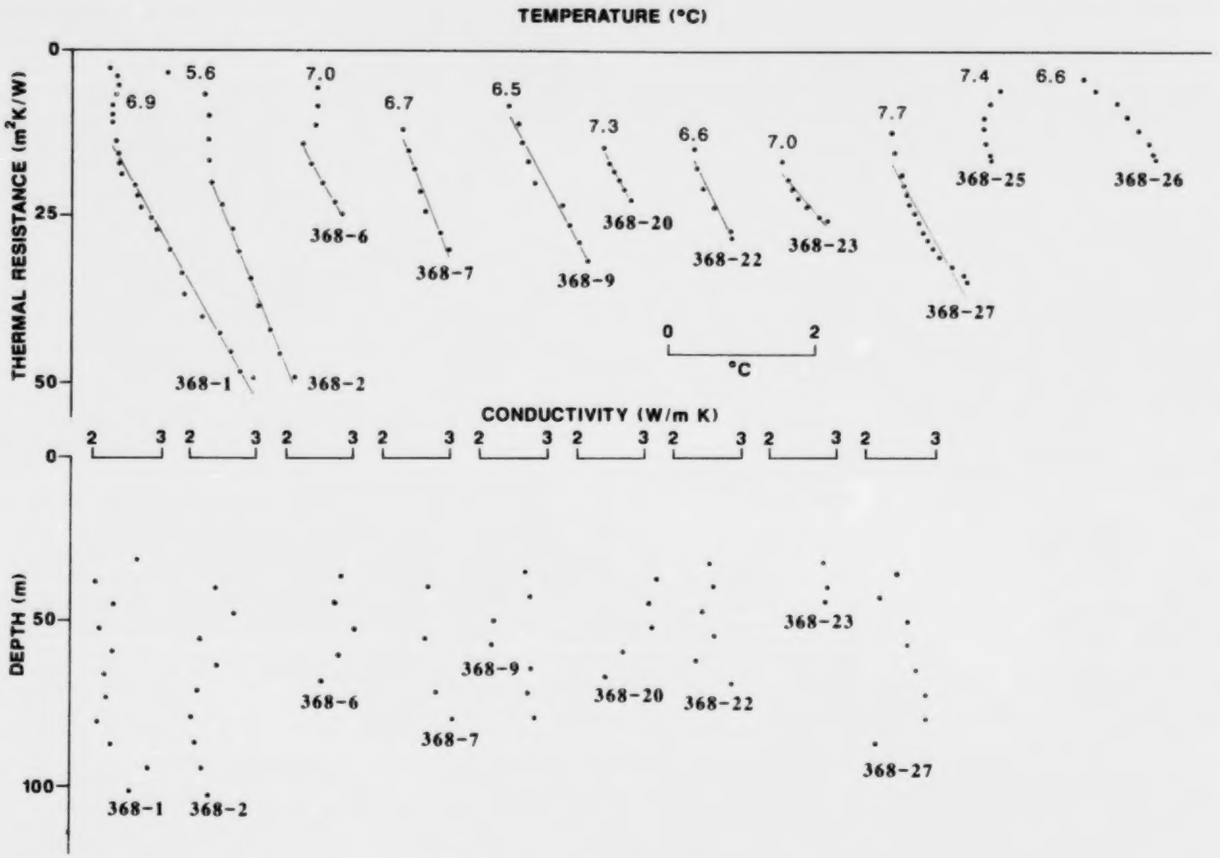

Figure 4. Plots as in Figure 2 for Cinola (series 368). Conductivities were not measured for holes 368-25 and -26 so the Bullard plots are based on the average thermal conductivity for the area.

Lyell Island (site 377): The temperature logs from two closely spaced boreholes located on steep side hills produced differing heat flux results. One had a very high surface intercept temperature, 8.0°C, indicating the influence of water flow. The other result, after topographic correction, is 56 mW m^{-2}.

HEAT GENERATION

The heat generation of sediments within a basin influences the basin temperatures (e.g. Keen and Lewis, 1982). Consequently, the heat generation of sediments was measured on cuttings from two of the offshore wells, Harlequin and Tyee. All heat generation values given in Table 1 are calculated for a standard density of 2.67 g cm^{-3}, which for the sediments must be modified to the time-verging density.

Representative samples from the major magmatic suites on the Queen Charlotte Islands including the Masset volcanics were measured and the heat generation is generally low. The heat generation on the east side of the basin on the youngest rocks is quite low and additional data from the older Coast Plutonic Complex (Lewis and Bentkowski, 1988) are very low. The sediments within the basin, derived from these sources, should also be low.

CONCLUSIONS

Because this geothermal study of the basin is not yet finished, any conclusions are preliminary. However the heat generation within the basin and in the magmatic rocks of the basin margins is definitely low. The pattern of heat flux, as revealed by the land measurements on the margins of the basin is low on the west side, increasing to average or slightly above average heat flux on the eastern side. The low values on the western side may be caused by oblique subduction, the limited extent of the low zone compared to that above the subducting Juan de Fuca Plate in southern B.C., reflecting the relatively young age and warmth of the oceanic crust being subducted.

The low heat generation of the Coast Plutonic Complex on the eastern margin and the present average heat flux of 75 mW m-2 produces high crustal temperatures at present under this region.

The one high heat flux of 110 mW m-2 from the shallow basin sediments may be caused by local processes, such as erosion and/or dewatering. Sand waves exist at depths close by Moresby Trough, and the sudden changes in BWT recorded require bottom currents.

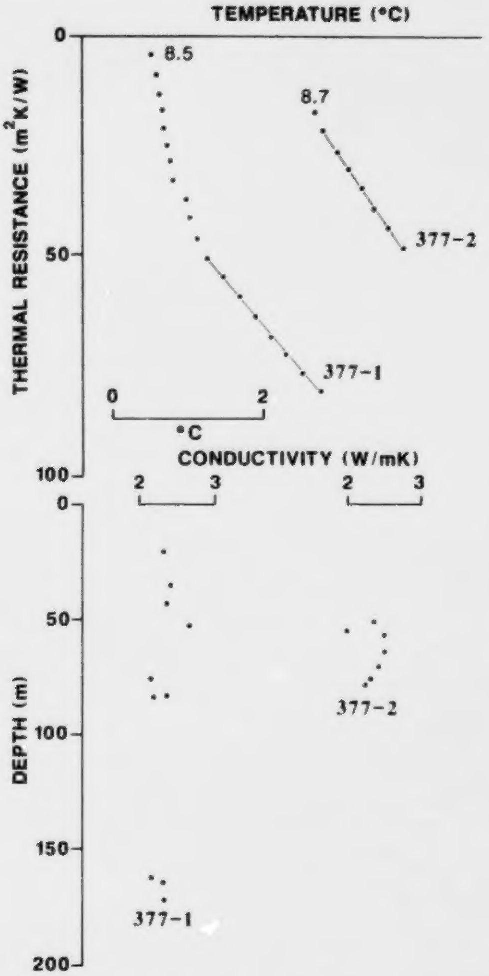

Figure 5. Plots as in Figure 2 for Lyell Island (series 377).

ACKNOWLEDGMENTS

We gratefully acknowledge the help and co-operation of City Resources (Canada) Ltd., Imperial Metals Corp., Placer Development Ltd., and Trader Resource Corp. in allowing us to make measurements in the exploration boreholes. We also thank R.G. Anderson and G.J. Woodsworth for supplying samples for heat generation measurements and Anne Wilkinson and Judith Baker for measuring the thermal conductivities of many samples.

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Table 1. Average heat generation

Series/ Site	Name	n	A μW/m^3	S.D. μW/m^3
	Queen Charlotte Islands			
200148	Sandspit	4	0.42	0.01
200149	Central Kano Pluton	4	0.64	0.02
200149	Shields Bay, pluton on North side	4	1.64	0.90
200149	Dykes north of Central Kano pluton	3	0.17	0.04
200149	Dykes along Phantom Creek	2	1.68	0.62
200150	Langara Island	9	1.03	0.26
200150	Pivot Mountain	8	0.29	0.05
300149	San Christoval	1	0.48	0.00
300149	Burnaby Island	4	0.67	0.41
300149	Carpenter Bay	2	1.22	1.29
300149	coeval dykes	4	0.66	0.51
200144	Haida sandstone, surficial samples	2	0.84	0.03
300136*	Masset volcanics	29	0.33	0.23
	Offshore wells			
300104*	Tyee: 215-560 m	3	0.42	0.04
	720-2190 m	13	0.80	0.12
	2240-3305 m	17	1.15	0.13
	3363, 3421 m	2	0.66	0.26
300115*	Harlequin: 400-3160 m	12	1.00	0.13
	below 3200 m	1	0.31	0.00
	Eastern side of basin			
315-1	Denny Island	13	2.75	0.86
315-2	Denny Island	19	1.95	0.44
300029*	Ecstall, Ponder and Quottoon plutons	8	0.82	0.52
200107*	Late Tertiary quartz feldspar porphyry opposite King Island	2	3.33	0.17
200107*	Cretaceous/Tertiary quartz monzonite east of King Island	7	0.54	0.04
300037*	King Island syenite, Miocene	4	1.19	0.35

n = number of samples;
A = average heat generation;
S.D. = 1 standard deviation
* Individual results from these series are already published in Lewis and Bentkowski (1988).

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Highlights of cruise END 88B on the continental shelf of western Canada[1]

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Luternauer, J.L., Barrie, J.V., and Conway, K.W., Highlights of cruise END 88B on the continental shelf of western Canada; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 127-128, 1989.

Abstract

High-resolution seismic profiling, sidescan sonar, sampling and remote oceanographic vehicle surveys were performed in selected areas on a four-week cruise that spanned the entire shelf of western Canada. Forty-three vibrocores, six Benthos piston cores, ten wide-diameter piston cores for geotechnical analyses, and one dredge haul were obtained. Seven camera stations were occupied. As a result of the cruise we have defined the extent of the Tertiary basin in Dixon Entrance, identified probable gas vents in Queen Charlotte Sound, mapped previously unrecognized sponge bioherms, confirmed the presence of drowned barrier island sand ridges in Hecate Strait, identified evidence of Quaternary faulting in northern Queen Charlotte Sound, and established the possible susceptibility of some sediments in the sound to liquefaction.

Résumé

Dans des régions sélectionnées, au cours d'une croisière de quatre semaines couvrant toute la plate-forme continentale de l'ouest du Canada, on a réalisé l'établissement de profils sismiques de haute résolution, des levés par sonar à balayage latéral, des échantillonnages, et des levés par submersibles télécommandés. On a recueilli 43 carottes par vibroforage, six carottes du benthos par carottier à piston, dix carottes de grand diamètre, destinées à des analyses géotechniques, par carottier à piston et un échantillon par dragage. On a occupé sept stations équipées de caméras. Les données recueillies grâce à cette croisière ont permis aux auteurs de définir l'étendue du bassin tertiaire dans l'entrée Dixon, d'identifier dans le détroit de la Reine-Charlotte des structures susceptibles d'être des évents de gaz, de cartographier des biohermes édifiés par des spongiaires et jusque-là non identifiés, de confirmer la présence de crêtes de sable appartenant à des îles-barrières submergées dans le détroit d'Hécate, d'identifier les indices de formation de failles au Quaternaire dans le nord du détroit de la Reine-Charlotte, et d'établir le potentiel thixotrope de certains sédiments du détroit.

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INTRODUCTION

During research cruise END 88B on *CFAV ENDEAVOUR* from 27 June to 22 July, 1988, investigations were performed in all major areas of the continental shelf of western Canada (Fig. 1). Primary objectives of the cruise were to continue sampling and surveying the shelf to identify potential geohazards to exploration and development. These operations are funded by the Office of Energy Research and Development and Frontier Geoscience Program.

ACTIVITIES AND ACCOMPLISHMENTS

Vancouver Island shelf

A 100 kHz E.G.&G. model 260 sidescan sonar system, Huntec ('70) Ltd. Deep-Tow seismic (DTS) profiler, and Fisheries and Oceans Canada Remote Operated Vehicle (ROV) manufactured by International Submarine Engineering Research Ltd. were used to investigate a suspected Quaternary fault off the southern part of Vancouver Island. The high resolution data collected on this cruise indicate that these features probably are scarps formed by erosion of Tertiary bedrock.

Dixon Entrance

An initial regional high resolution geophysical survey utilizing sidescan sonar, Huntec DTS profiling and 7.6 cubic cm airgun seismic served to define the surficial geology of the area. Two Benthos piston cores and 2 vibrocores were collected. Results indicate that several hundred metres of Quaternary sediments have accumulated over Tertiary bedrock. Over most of the area the sea bed is heavily blanketed by gravels and coarse sand.

Hecate Strait

A survey which simultaneously collected sidescan sonar, Huntec DTS profiles, and 7.6 cubic cm airgun seismic data was completed. One large-diameter (9.9 cm I.D.) piston core, four standard diameter Benthos piston cores and 30 vibrocores were collected and 1 camera station occupied. Drowned barrier islands have been identified and will contribute to our knowledge of the sea level history of the shelf (Barrie and Bornhold, in press; Luternauer et al., in press). The first lithologic control is now available for the extensive network of seismic profiles previously collected on this part of the shelf (Barrie, 1988). In the course of sampling for investigations of sediment dispersal patterns and rates, sediments with high concentrations of heavy minerals were discovered. These are being assayed for Ti and Zr. Anomalous features recognized in acoustic records of the sea floor, collected during this and previous cruises to Hecate Strait and Queen Charlotte Sound, were found to be extensive fields of sponge bioherms (Conway et al., 1989). Trials of the Fisheries and Oceans Canada ROV proved it to be an effective tool for investigating debris flows and geological contacts on the shelf floor to a water depth of 130 m.

Queen Charlotte Sound

A high resolution geophysical survey using sidescan sonar, Huntec DTS seismic profiling and 7.6 cubic cm airgun was made. Nine large-diameter piston cores, and 11 vibrocores were collected and 6 camera stations were occupied. Evidence of an extensive wave cut, gravel-mantled terrace about 100 m below sea level on the north side of a bank at the centre of the sound corroborates evidence from the southern part of the sound (Luternauer et al., in press) indicating that sea level fell to at least that level during the late Quaternary. Preliminary analyses of the slope and sediment stability in the sound using seven of the collected cores (Zavoral et al., 1989) suggests that some sediments are susceptible to liquefaction. High resolution seismic profiles collected during this cruise and previously acquired records suggest that syndepositional faulting has occurred during the late Quaternary in the northern part of the sound (Moslow et al., 1989). Probable gas vents have been identified in two areas in the sound. Samples were collected for gas analysis from one of the sites.

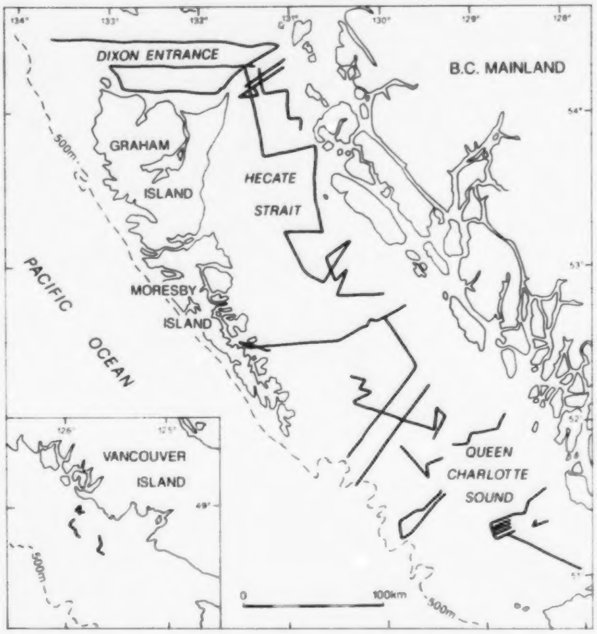

Figure 1. Research cruise END 88B tracklines.

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Sponge bioherms on the continental shelf of western Canada[1]

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Conway, K.W., Barrie, J.V., and Luternauer, J.L., Sponge bioherms on the continental shelf of western Canada; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 129-134, 1989.

Abstract

Large areas (>700 km²) of the seabed on the continental shelf of western Canada are discontinuously blanketed by bioherms dominated by species of Hexactinellid sponges, including Chonelasma calyx *and* Aphrocallistes vastus. *The bioherms are up to 10 m thick and form complexes several kilometres in width, between 150-250 m water depth. These bioherms trap Holocene silty clay on otherwise relict expanses of seafloor and form some of the most significant Holocene deposits on the mid-shelf.*

Résumé

De vastes étendues (>700 km²) du fond marin sur la plate-forme continentale de l'ouest du Canada sont recouvertes en discontinuité par des biohermes dominées par des espèces d'éponges Hexactinellides, en particulier Chonelasma calyx *et* Aphrocallistes vastus. *Les biohermes atteignent parfois 10 m d'épaisseur et forment des complexes de plusieurs kilomètres de large, à une profondeur d'eau comprise entre 150 et 250 m. Ces biohermes piègent des argiles silteuses de l'holocène sur des étendues du fond marin par ailleurs résiduelles, et forment quelques-uns des dépôts holocènes les plus importants de la partie médiane de la plate-forme continentale.*

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INTRODUCTION

The physiography of the central British Columbia continental shelf, comprising Queen Charlotte Sound and southern Hecate Strait, is dominated by troughs floored by clayey silts and fine sands, and banks capped by sands and gravels (Luternauer and Murray, 1983; Barrie, 1988). Queen Charlotte Sound is crossed by three troughs, the most northerly of which extends into Queen Charlotte Sound from Hecate Strait (Fig. 1). An extensive piston coring and radiocarbon dating program has shown that the sediments flooring Mitchell's Trough[1] and Goose Island Trough[1] are largely Late Wisconsinan in age, the Holocene section being thin or absent (Conway and Luternauer, 1985). Much of southwestern Moresby Trough[1] is floored by Holocene muds (Luternauer and Conway, 1986). Shallow subsurface sample data from the Hecate Strait part of Moresby Trough are unavailable at present.

During research cruise PAR86 several acoustically anomalous seabed features were seen on high-resolution seismic and sidescan sonar profiles collected in Goose Island Trough (Fig. 1). Amorphous-appearing, mound or ridge-like structures cover areas of the stratified, acoustically dense trough floor. A re-examination of geophysical data collected previously suggested a widespread distribution of this type of feature. Cruises undertaken in support of the Frontier Geoscience Program (END87A; END88B) obtained cores, photographs and additional geophysical data in areas where the mound-like structures occur. These new data have allowed the identification of these anomalies as well as recognition of their distribution and environmental significance.

METHODS

High resolution geophysical surveying was done in the study area using 100 kHz E.G.&G. model 260 sidescan sonar system and a Huntec ('70) Ltd. Deep-Tow seismic profiler during cruise END88B in July, 1988. Cores were taken using a Benthos piston corer in August, 1987 on cruise END87A. Seabed photography was accomplished using an UMEL underwater camera system during cruise END88B in July, 1988. Distribution of mound structures was determined by examination of Klein sidescan sonographs, Atlantic Geoscience Centre sidescan sonographs and Huntec DTS profiles previously collected during cruises HUD81, VEC84B, END84B and PAR86.

RESULTS

On Huntec DTS profiles the features appear as somewhat amorphous ridges or mounds 1-10 m thick (based on a sound velocity of 1500 m/sec.). They have an irregular surface and show no recognizable internal structure (Fig. 2). The base of the mounds commonly appear to lie in depressions, in some cases interpreted to be relict iceberg furrows. Seismic data indicate that the features are generally underlain by glaciomarine or till surfaces. Sidescan sonar images reveal the mounds to be of various sizes and shapes. The smaller mounds are roughly circular in plan view and appear to coalesce to form larger, irregular shaped bodies (Fig. 2). Isolated mounds range from <10 to >600 m in diameter whereas the larger mound complexes may be many kilometres across. Sonographs also indicate that the mound surfaces are variable in reflectivity, with some portions of mounds appearing 'brighter' than adjoining areas. This gives the features a somewhat crinkled appearance.

Seabed photographs taken on a mound in Hecate Strait show that mound surfaces range from being densely colonized with siliceous sponges to sediment covered, barren patches which are devoid of sponges (Fig. 3). Even on mound surfaces which display abundant, apparently healthy sponges, sediment-clotted portions of sponges are visible. Fish and crabs are also evident in several photographs (Fig. 3).

Piston core END87A-151, collected on the flank of a mound complex in Goose Island Trough, sampled a 3.1 m sequence of olive silty clay with abundant siliceous sponge fragments and fine sponge debris overlying 0.3 m of laminated dark grey sandy silt (Fig. 4). The trigger core, which more commonly retains the uppermost sequence of sediments than does the main piston core from the same site, recovered a 0.15 m interval of living sponge overlying olive silty clay with abundant sponge debris. Species of Hexactinellid sponges present were *Chonelasma calyx* and *Aphrocallistes vastus* (W. Austen, pers. comm., 1988). Sand fractions (63 microns to 2 mm) of subsamples of the olive silty clay contained little clastic material, being composed primarily of agglomerated mud clasts, sponge fragments and spicules, and foraminifera.

DISCUSSION

The Hexactinellid sponges colonizing the surfaces of the mounds appear to become clotted with mud particles. Core data indicate a succession of sponges form the basic structure of the mounds and that these mounds are actively accreting sediment on their surfaces today. These observations suggest that the mounds develop as siliceous sponges trap fine suspended detritus. The mounds and mound complexes are thus thought to be bioherms because they are constructed as a result of the filter-feeding mode of life of the sponges. This is supported by the absence of any recent fine sediment away from the mound sites and also by the marked isolation of individual mounds.

The variability in the reflectivity of mound surfaces noted on sidescan sonar records may be due to areas of upright, unsedimented sponges being more reflective then adjacent areas of sediment-covered mound. This variability may also be due to elevation differences across the bioherm surface.

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[1] The geographic names Mitchell's Trough and Goose Island Trough are informal and have not been approved by the Advisory Committee on Underseas Feature Names.

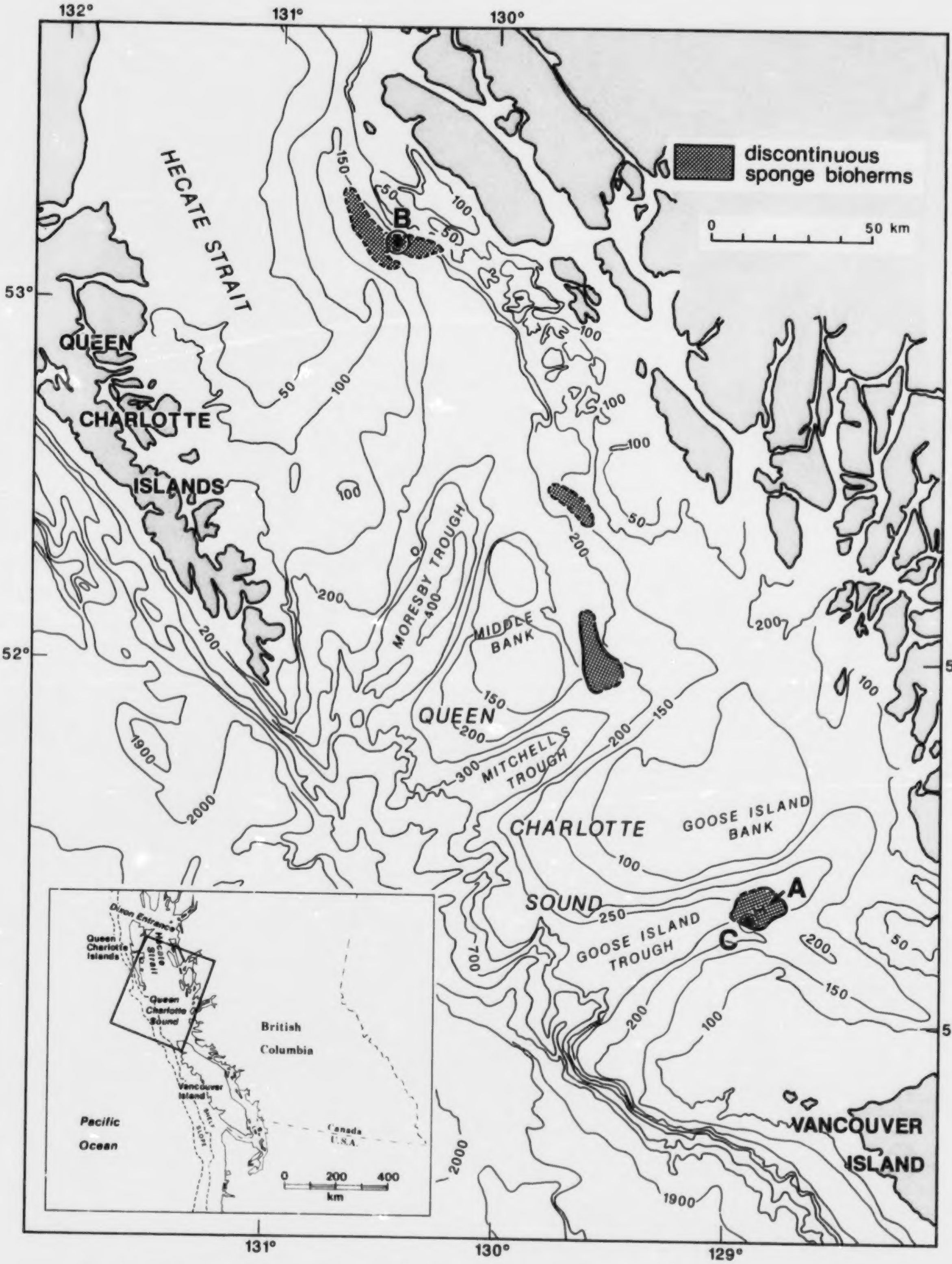
132°
131°
130°
53°
52°
52°
51°
131°
130°
129°
discontinuous sponge bioherms
0
50 km
HECATE STRAIT
QUEEN
CHARLOTTE
ISLANDS
MORESBY TROUGH
MIDDLE BANK
QUEEN
MITCHELL'S TROUGH
CHARLOTTE
SOUND
GOOSE ISLAND BANK
GOOSE ISLAND TROUGH
VANCOUVER ISLAND
A
B
C
50
100
150
200
250
300
400
700
1900
2000
Dixon Entrance
Queen Charlotte Islands
Hecate Strait
Queen Charlotte Sound
British Columbia
Vancouver Island
Pacific Ocean
Canada
U.S.A.
0
200
400
km

Figure 1. Western Canadian continental shelf study area; A: location of seismic and sidescan profiles shown in Figure 2; B: location of seabed photographs shown in Figure 3; C: location of core END87A-151.

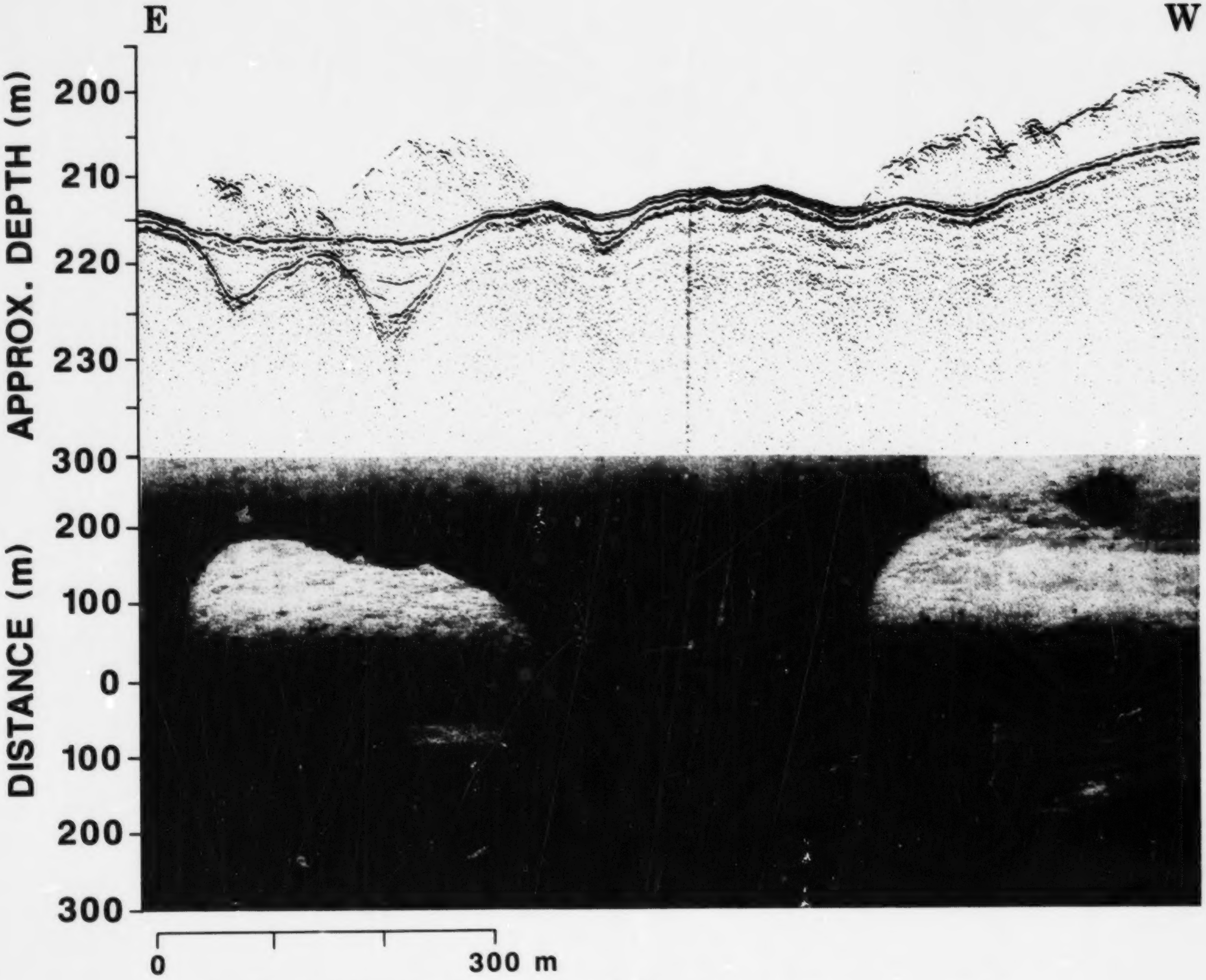

Figure 2. Huntec Deep Tow seismic profile and E.G.&G. sidescan sonograph of sponge mounds in southern Queen Charlotte Sound.

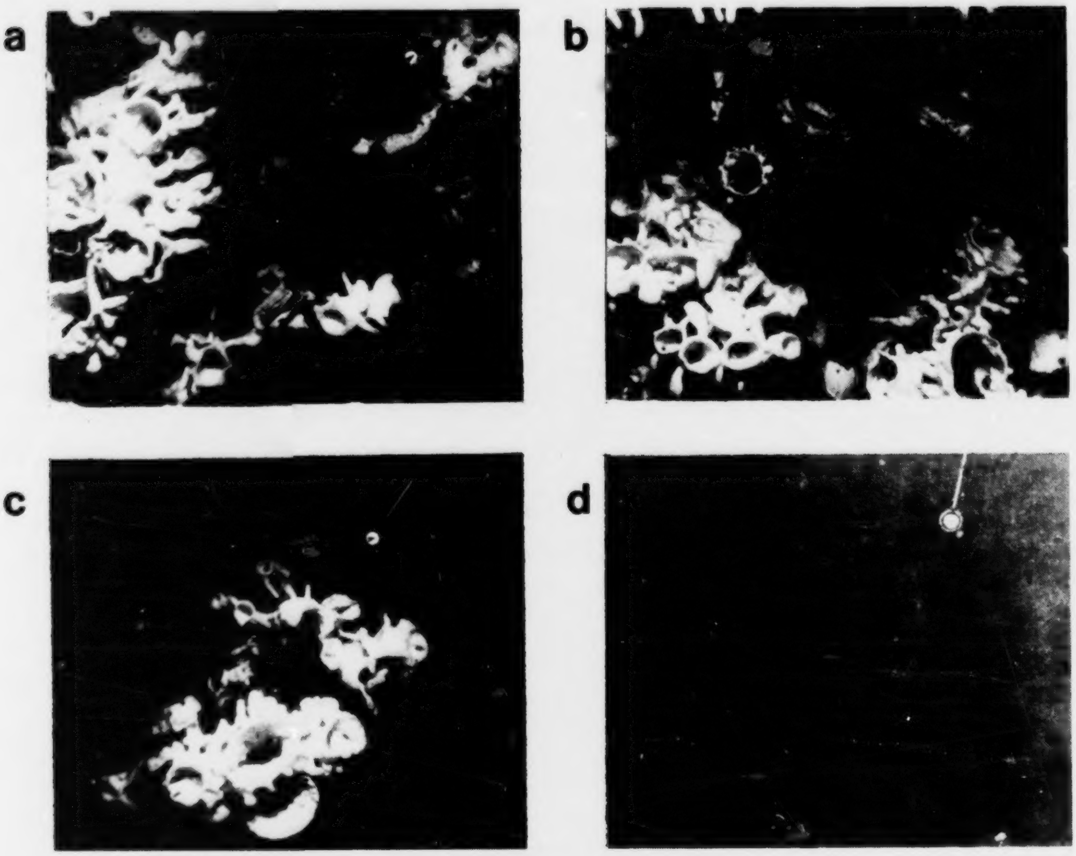

Figure 3. Surface of Hecate Strait sponge mound (165 m water depth). (a): Abundant siliceous sponges with sediment-clotted sponges at centre; (b): school of fish among sponges; (c): isolated sponges on less densely colonized mound surface; (d): completely sediment-clotted area of sponge mound. Compass vane is 30 cm long.

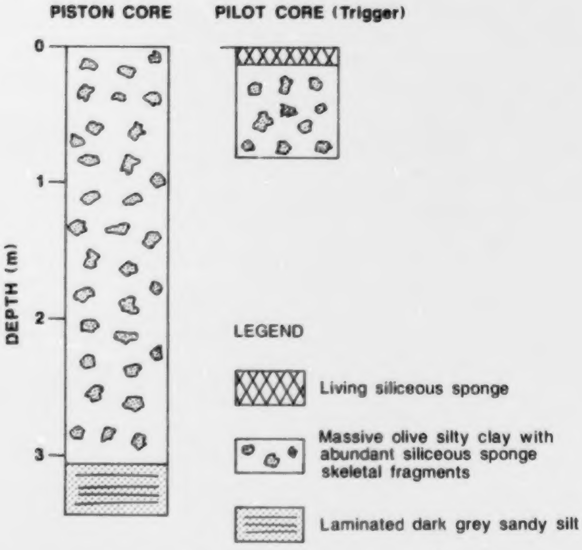
PISTON CORE
PILOT CORE (Trigger)
DEPTH (m)
0
1
2
3
LEGEND
Living siliceous sponge
Massive olive silty clay with abundant siliceous sponge skeletal fragments
Laminated dark grey sandy silt

Figure 4. Lithology of core END87A-151.

Although no radiocarbon dates are available from cores from the bioherms, some seabed morphological features, regional stratigraphic relationships and properties of the mound matrix sediment itself allow some inferences about the age of these structures. The bioherms rest on iceberg furrowed surfaces in several areas. These furrows are thought to be of Late Wisconsinan age (Luternauer and Murray, 1983). Sediments underlying mounds are similar to Late Wisconsinan glaciomarine and transgressive sandy mud sequences previously cored and radiocarbon dated (Luternauer et al., unpub. data). The matrix sediment of the bioherms is an olive, silty clay resembling in colour and texture Holocene deposits sampled and dated elsewhere on the shelf (Luternauer et al., unpub. data).

The fact that the bioherms are concentrated in the three major troughs which cross the continental shelf suggests that fine sediment is delivered to the bioherm sites by bottom currents. The sediment incorporated into the bioherms is the only Holocene sediment present in much of Mitchell's and

Goose Island troughs, indicating that in these areas the sponge mounds are exerting a fundamental control on modern sedimentation.

The rate of growth of these bioherms, their ecology and relationship to local oceanogaphic processes will be examined in detail in future studies.

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Neotectonics and sedimentation patterns in Moresby Trough, central continental shelf of western Canada[1]

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Moslow, T.F., Luternauer, J.L., and Conway, K.W., Neotectonics and sedimentation patterns in Moresby Trough, central continental shelf of western Canada; in Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 135-140, 1989.

Abstract

Analysis of high resolution seismic profiles from the central British Columbia continental shelf provides substantial evidence for Quaternary faulting along the northwestern margin of Moresby Trough. A divergence of reflectors, thickening of seismic units, and concavity of reflectors suggestive of drag are seen along the downthrown side of normal faults in the study area. Faulting appears to be syndepositional. Possibly, some of the faults are listric normal. Fault traces commonly terminate below the seabed. Deformation of Quaternary sediments due to faulting is non-brittle in nature, and maximum offset of reflectors thus far seen is 2.5 m.

It is suggested that the Quaternary faulting observed is a product of movement along antecedent listric normal faults that have been reactivated by glacial loading and isostatic rebound. The potential hazards posed by faulting to seafloor development of any kind are serious and numerous.

Résumé

L'analyse des profils sismiques de haute résolution, établie pour la partie centrale de la plate-forme continentale de la Colombie-Britannique, prouve de façon substantielle qu'il y a eu formation de failles au Quaternaire sur la marge nord-ouest de la fosse de Moresby. On observe dans la région étudiée, en suivant le compartiment affaissé des failles normales, une divergence des miroirs, un épaississement des unités sismiques, et une concavité des miroirs qui semble indiquer un étirement. Il semble que la formation des failles ait été contemporaine de la sédimentation. Il est possible que quelques-unes des failles soient listriques normales. Les traces des failles se terminent généralement au-dessous du fond marin. La déformation des sédiments quaternaires causée par les failles est de type non fragile, et jusqu'à présent, le rejet maximum observé des couches-miroirs est de 2,5 m.

On propose que les failles quaternaires observées résultent de mouvements le long de failles listriques normales formées antérieurement, qui ont été réactivées par la surcharge des glaciers et le redressement isostatique du terrain. Les dangers potentiels que représente la formation de failles pour une mise en valeur quelconque du fond marin sont sérieux et nombreux.

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INTRODUCTION

Previous investigations suggested that Moresby Trough is one of the few, and perhaps only, major physiographic elements of the central British Columbia continental shelf that can be attributed to a tectonic-structural origin (Yorath and Chase, 1981). Although this is a seismically active area, sub-bottom evidence of large scale normal faulting from seismic profiles is inconclusive (Luternauer and Murray, 1983). However, Deep-Tow high resolution seismic profiles collected during 1984 and 1988 from Moresby Trough, and analyzed for this investigation, show evidence of normal, syndepositional faulting within the upper Quaternary section. This report examines in detail some of the initial observations and evidence of neotectonics within the Quaternary sediments of Moresby Trough. In addition, the possible causes and mechanisms of this structural activity-tectonism are discussed.

This investigation will add to the present understanding of the Quaternary evolution of Queen Charlotte Sound in general, and Moresby Trough in particular. Additional objectives include: 1) a determination of the cyclicity, variability and distribution of Quaternary faults within the Moresby area; 2) identification of those areas that show evidence of recent (Holocene) syndepositional faulting; and 3) a determination of the impacts on sedimentation patterns and seafloor instability in Moresby Trough from the observed neotectonism.

GEOLOGICAL SETTING

Moresby Trough is one of four large-scale, linear, bathymetric depressions that dissect Queen Charlotte Sound (Fig. 1). These troughs average about 20 km in width within the 200 m bathymetric contour, and vary from some 50-100 km in length, cutting obliquely across the entire width of the central British Columbia continental shelf (Fig. 1). Broad shallow banks capped by sand and gravel separate the troughs from one another. It is these features that form the principal physiographic elements of Queen Charlotte Sound. With the exception of Moresby, the origin of the troughs has been attributed solely to scour by grounded ice during Quaternary glaciations (Luternauer and Murray, 1983). Alternatively, a tectonic-structural origin has been proposed for Moresby Trough by Yorath and Chase (1981). These authors attribute the trend and positioning of the trough to "listric crustal-pervasive normal faults" that terminate against the suture zone of two allochthonous terranes underlying the Queen Charlotte Sound area. An air gun seismic profile line across outer Moresby Trough (line F-F' in Luternauer and Murray, 1983) was cited by Yorath and Chase (1981) as evidence of the normal faulting along the trough margin (Fig. 2). Thus, evidence of large-scale faulting in Queen Charlotte Sound may exist. However, it is interesting to note that, although the sound is adjacent to one of the most seismically active areas in Canada (Milne et al., 1978), no earthquakes of magnitude 5 or greater have occurred within the sound during the period 1899-1977 (Rogers, 1982).

Recent work on a more localized and detailed level has identified shallow biogenic gas and steep (10-15°) sediment fans along the eastern margin of Moresby Trough (Luternauer and Conway, 1986). Such features were recognized by them as potential constraints to hydrocarbon exploration and development in Queen Charlotte Sound. Active faulting on almost any scale, poses a serious threat to industry-based exploration or infrastructure at all levels of involvement.

METHODS

About 320 line-km of Deep-Tow high resolution seismic profiles across the Moresby Trough are available for the purposes of this investigation. These data were collected during research cruises aboard the *C.S.S. HUDSON* in 1984 and *C.F.A.V. ENDEAVOUR* in the summer of 1988. Profile lines were run parallel and oblique to the axis of the trough at a 6 km spacing. A Huntec Deep-Tow system (H.D.T.S.) was employed in the acquisition of high resolution seismic profiles. Profile lines were run at a cruising speed of 4.0 knots. Navigation systems employed included Loran C and Global Positioning System (G.P.S.).

Hand drawn tracings of representative seismic profiles were made to highlight individual reflectors. This technique was employed to critically analyze individual reflectors and/or seismic units for bed displacement, offset, drag or changes in thickness (see Fig. 3a and b for an example).

PRELIMINARY RESULTS

Faulting of Quaternary sediments is apparent in Moresby Trough. Evidence for the syndepositional nature of the faulting includes a thickening of the sedimentary section between individual reflectors along the downthrown side of the fault trace(s) (Fig. 3a, 3b and 4) and drag on individual beds, as observed by the concavity of certain reflectors where they abut the downthrown side of a normal-fault trace (Fig. 4).

Quaternary faulting is best observed along the western flank of a depositional lobe that parallels the longitudinal axis of Moresby Trough. The seismic profiles shown in Figures 3a,b and 4 are found in this locality. Their relative positions are shown on the air gun record in Figure 2.

The deformation of individual reflectors, and the subtle thickening of sedimentary sections observed in seismic profiles, suggest that the Quaternary normal faulting is non-brittle. Thus far, the maximum offset observed between reflectors is about 2.5 m (Fig. 3a, b). Two normal faults are shown in Figure 3a, b with only a minor offset of individual reflectors. The westward divergence of individual reflectors between the two fault traces is evidence of the thickening of Quaternary sedimentary units as a function of syndepositional fault movement. While this normal faulting was active during the later Quaternary it was apparently not active during the late Holocene everywhere in Moresby Trough. This is shown by the lateral continuity of reflectors above the normal fault traces shown in the profile in Figures 3a and b.

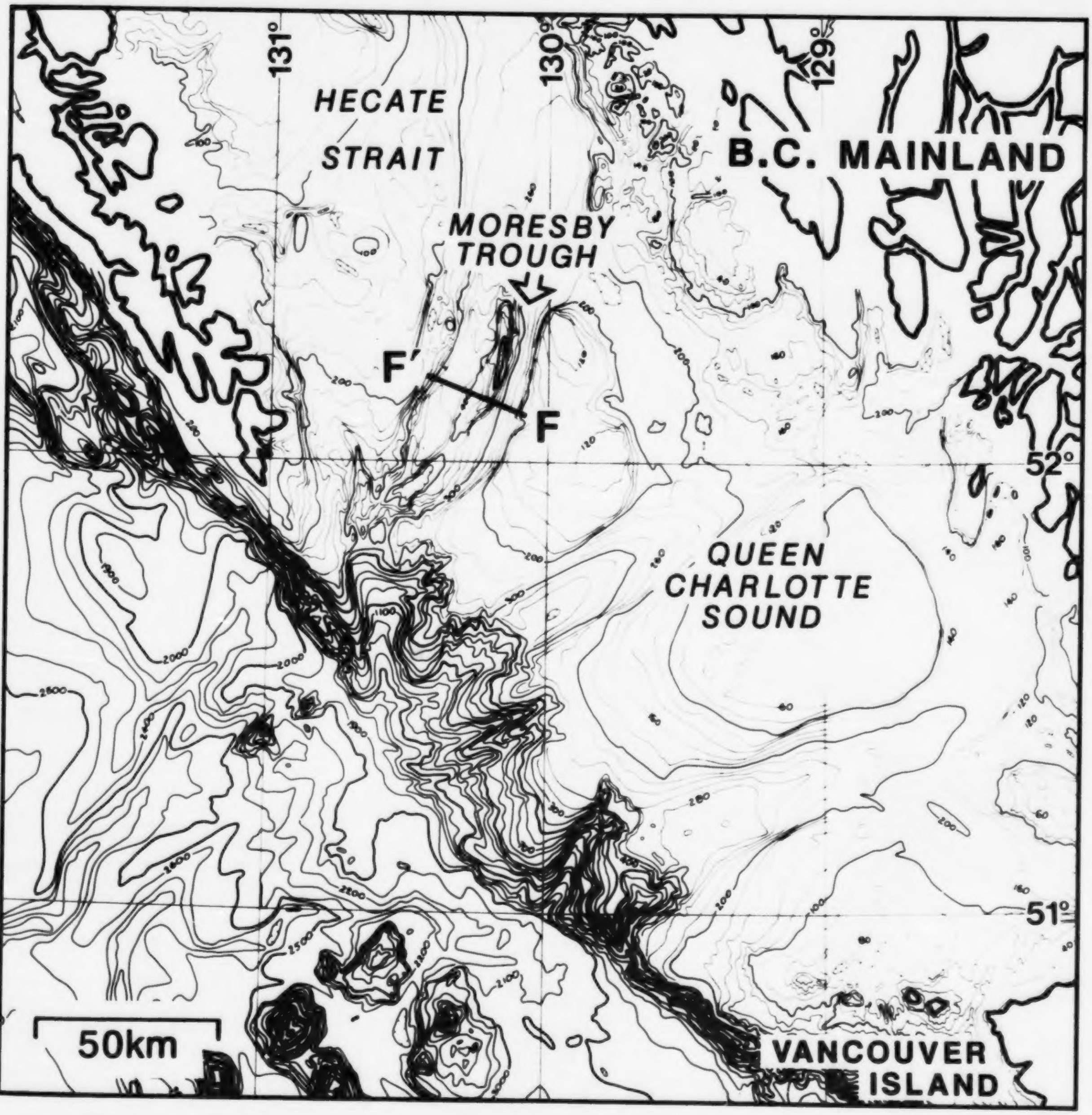

HECATE
STRAIT
131°
130°
129°
B.C. MAINLAND
MORESBY
TROUGH
F′
F
52°
QUEEN
CHARLOTTE
SOUND
51°
50km
VANCOUVER
ISLAND

Figure 1. Bathymetric and physiographic map of the central British Columbia continental shelf showing location of Moresby Trough along the northwestern margin of Queen Charlotte Sound (from Luternauer and Murray, 1983).

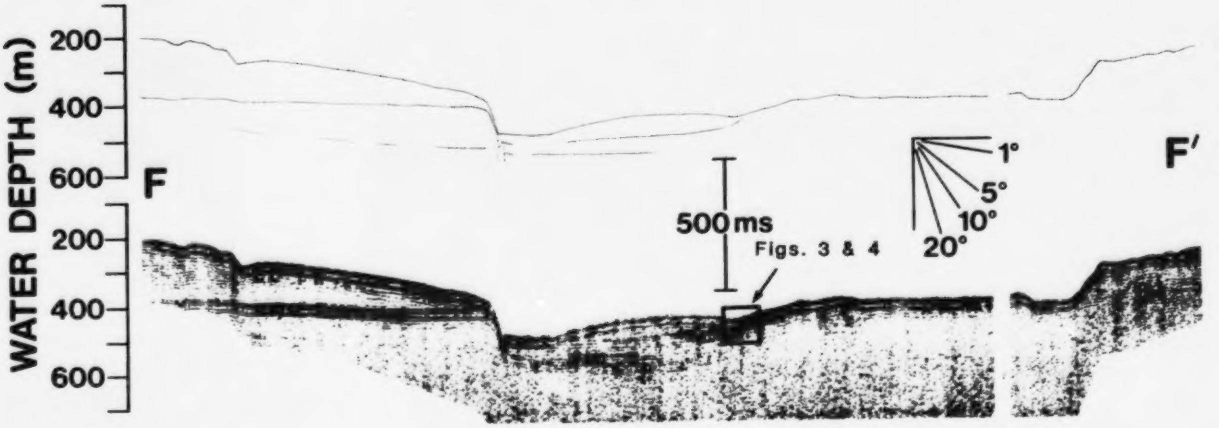
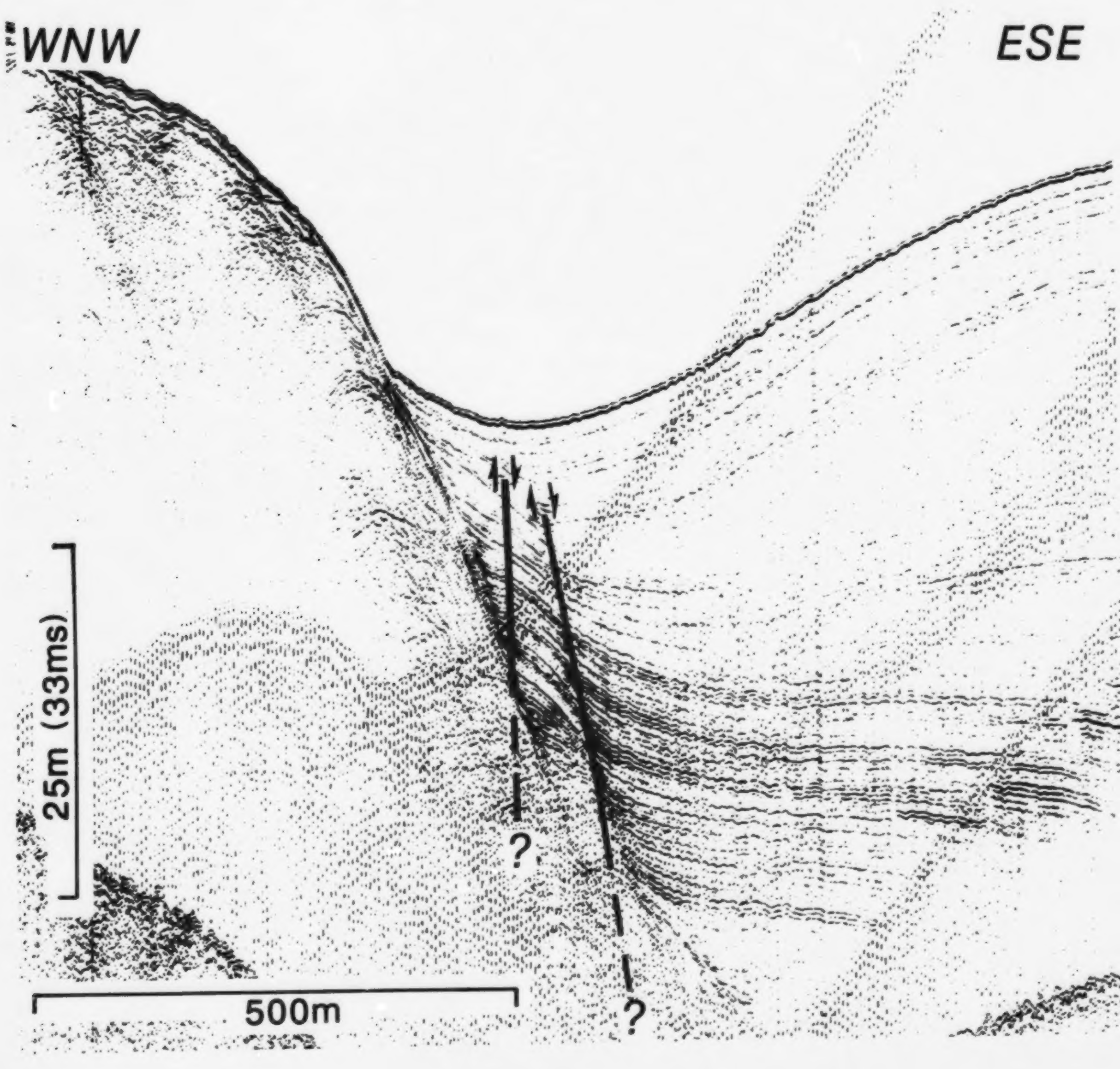

WATER DEPTH (m)
200
400
600
200
400
600
F
F′
500 ms
Figs. 3 & 4
1°
5°
10°
20°

Figure 2. Air gun seismic profile across the outer Moresby Trough showing relative location of high resolution seismic profiles in Figures 3a, b and 4. From profile F-F' of Luternauer and Murray (1983).


WNW
ESE
25m (33ms)
500m
?
?

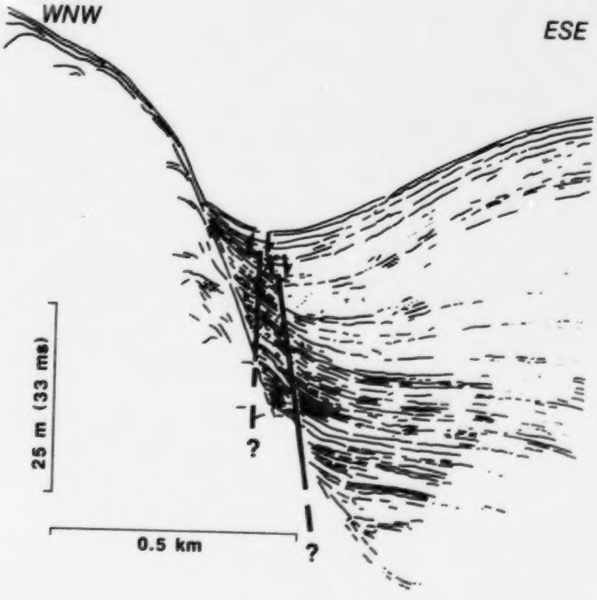
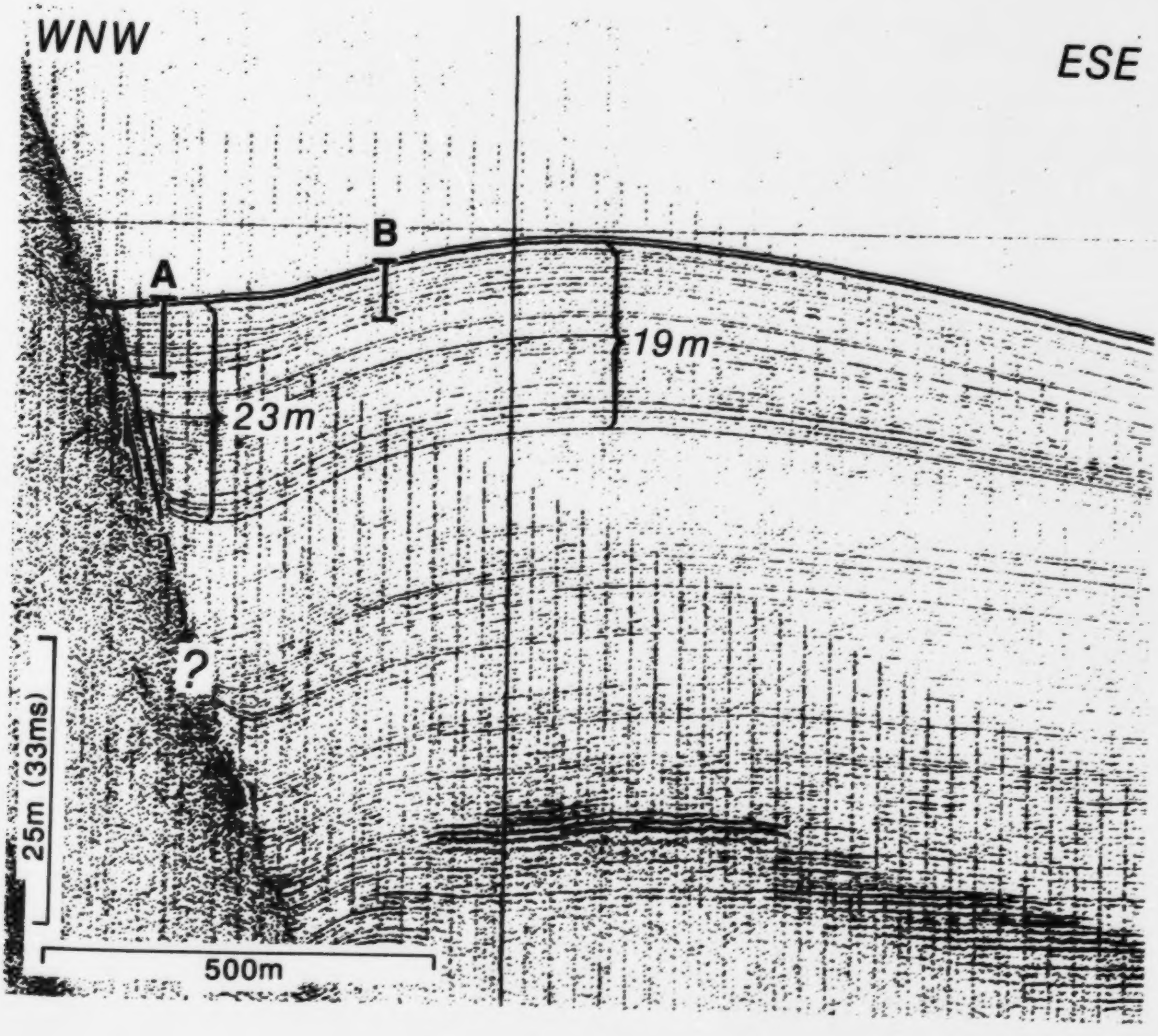


Figure 3a. (facing page bottom) Huntec D.T.S. high resolution seismic profile in about 400 m water depth along the northwestern margin of Moresby Trough. Profile line is oriented oblique to the trough axis. Note convergence and divergence of reflectors between normal fault traces.

Figure 3b. (left) Hand drawn tracing of seismic reflectors from profile shown in Figure 3a. See text for interpretation.

Figure 4. (below) Huntec D.T.S. high resolution seismic profile in about 400 m water depth along the northwestern margin of Moresby Trough. Note thickening to west of upper seismic units and divergence and concavity of reflectors along downthrown block of normal fault. Profile is perpendicular to the trough axis.



There is no evidence of any offset between reflectors in the Quaternary section of the seismic profile in Figure 4. There is an appreciable thickening of the section, however, from east to west along the downthrown side of the fault trace. The amount of drag along this downthrown side of the fault increases with depth, suggesting that this fault is listric normal. The uppermost set of reflectors in this seismic profile represents the latest Quaternary sedimentary section which thickens approximately 4 m in an westerly direction along the downthrown margin of the fault trace. This unit thickens from 19 to 23 m over a distance of about 0.65 km. Note also the divergence of individual reflectors within this unit to the west, proximal to the observed fault. This trend is best seen within the uppermost part of the subbottom, labelled as 'A' and 'B', where the sedimentary section thickens from 4.5 to 6.5 m over a distance of some 0.3 km. If these depositional trends were a product of sedimentary processes alone (ie. suspension or traction deposition) then the bathymetric high, rather than the low, should be associated with the thickest accumulation of sediment. Such is not the case.

DISCUSSION AND CONCLUSIONS

Normal faulting, and possibly listric normal faulting, is observed within the Quaternary sediments of Moresby Trough. In all cases examined, the faulting is non-brittle and syndepositional. There is evidence of faulting either: a) throughout the Quaternary section including the Holocene, or b) within the upper Quaternary section but not the Holocene.

It is possible that the faulting can be attributed to the reactivation of antecedent normal faults that were reactivated by glacial loading and isostatic rebound of the shelf during the Pleistocene. Future correlations of Huntec Deep-Tow seismic profiles with air gun records across the Moresby Trough may be able to address this problem. If this hypothesis is correct, then there is likely a certain periodicity or cyclicity to the observed normal faulting that is linked to glacial episodes during the late Tertiary and Quaternary. In addition, it is likely that not all parts of the Moresby Trough area have achieved equilibrium with regards to isostatic loading or rebound, and are still actively experiencing normal faulting.

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Geotechnical properties of sediments on the central continental shelf of western Canada[1]

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Zavoral, D.Z., Campanella, R.G., and Luternauer, J.L., Geotechnical properties of sediments on the central continental shelf of western Canada; in *Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 141-148, 1989.*

Abstract

Seven piston cores collected from Queen Charlotte Sound on the continental shelf of western Canada were examined for the following geotechnical properties: peak and remoulded undrained shear strength, sensitivity, water content, bulk density, and Atterberg limits. Sediment characteristics, despite high sensitivity and liquidity index values, indicate that most slopes are statically stable due to low slope angles and sufficient peak undrained shear strengths. However, some of the sediment sampled has a low plasticity index, indicating possible susceptibility to liquefaction. Many submarine slopes may therefore be dynamically unstable. We recommend cone penetration testing of the cohesionless sediments in Mitchell's Trough which are not amenable to piston coring but may be highly unstable.

Résumé

On a examiné sept carottes provenant du détroit de la Reine-Charlotte, recueillies par carottier à piston sur la plate-forme continentale de l'ouest du Canada, aux fins de déterminer les propriétés géotechniques suivantes: valeurs de pointe et de remoulage de la résistance au cisaillement dans des conditions non drainées, sensibilité, teneur en eau, densité apparente et limites d'Atterberg. Les caractéristiques du sédiment, malgré des valeurs élevées de la sensibilité et de l'indice de liquidité, indiquent que la plupart des pentes sont statistiquement stables, car elles ont un gradient faible et une résistance de pointe au cisaillement dans des conditions non drainées qui est suffisante. Cependant, quelques-uns des sédiments échantillonés ont un faible indice de plasticité, signe d'une susceptibilité possible à la liquéfaction. Il est donc possible que de nombreuses pentes sous-marines soient dynamiquement instables.

On recommande d'effectuer quelques essais de pénétrabilité au cône sur les sédiments sans cohésion de la fosse de Mitchell, qui ne se prêtent pas au forage à l'aide d'un carottier à piston mais peuvent être très instables.

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INTRODUCTION

Queen Charlotte Sound (Fig. 1) is adjacent to one of the most seismically active areas in the world (Milne et al., 1978). Although the sediment distribution on the seafloor is well known (Luternauer and Murray, 1983) no systematic assessment has been made of the stability of the seafloor with respect to static or dynamic conditions.

The objective of this report, is to give the preliminary results of laboratory testing of core samples collected in 1988 in the sound to establish some basic geotechnical properties of these sediments and present a preliminary analysis. Future reports will present a more rigorous assessment of the stability of the seafloor.

GEOLOGICAL SETTING

The physiography of Queen Charlotte Sound consists primarily of banks capped with gravel and sand and troughs floored with gravel, sand and mud (Luternauer and Murray, 1983). Glacial processes have largely determined both the morphology and sediment distribution in the sound. These have been subsequently modified and reworked, respectively, by a higher energy oceanic regime which existed at a time of lowered sea levels (Luternauer et al., in press). The present sedimentation within Queen Charlotte Sound consists of olive-green organic muds which are accumulating primarily in the troughs, away from the shelf break.

FIELD AND ANALYTICAL METHODS

Piston cores were obtained at seven sites from the C.F.A.V. *ENDEAVOUR* (cruise END88B) from June 11-23, 1988 (Table 1, Fig. 1). Sample locations were chosen to emphasize:

1. sites having loose or soft sediments which could be prone to slope instability and could be penetrated readily by the piston corer (slopes with coarse sediment (sand and diamict) could not be sampled adequately with available corers).
2. sites where sampled units can be traced laterally for some distance using seismic profiles and thus permit tentative extrapolation of defined geotechnical properties from sampled areas to other sites.

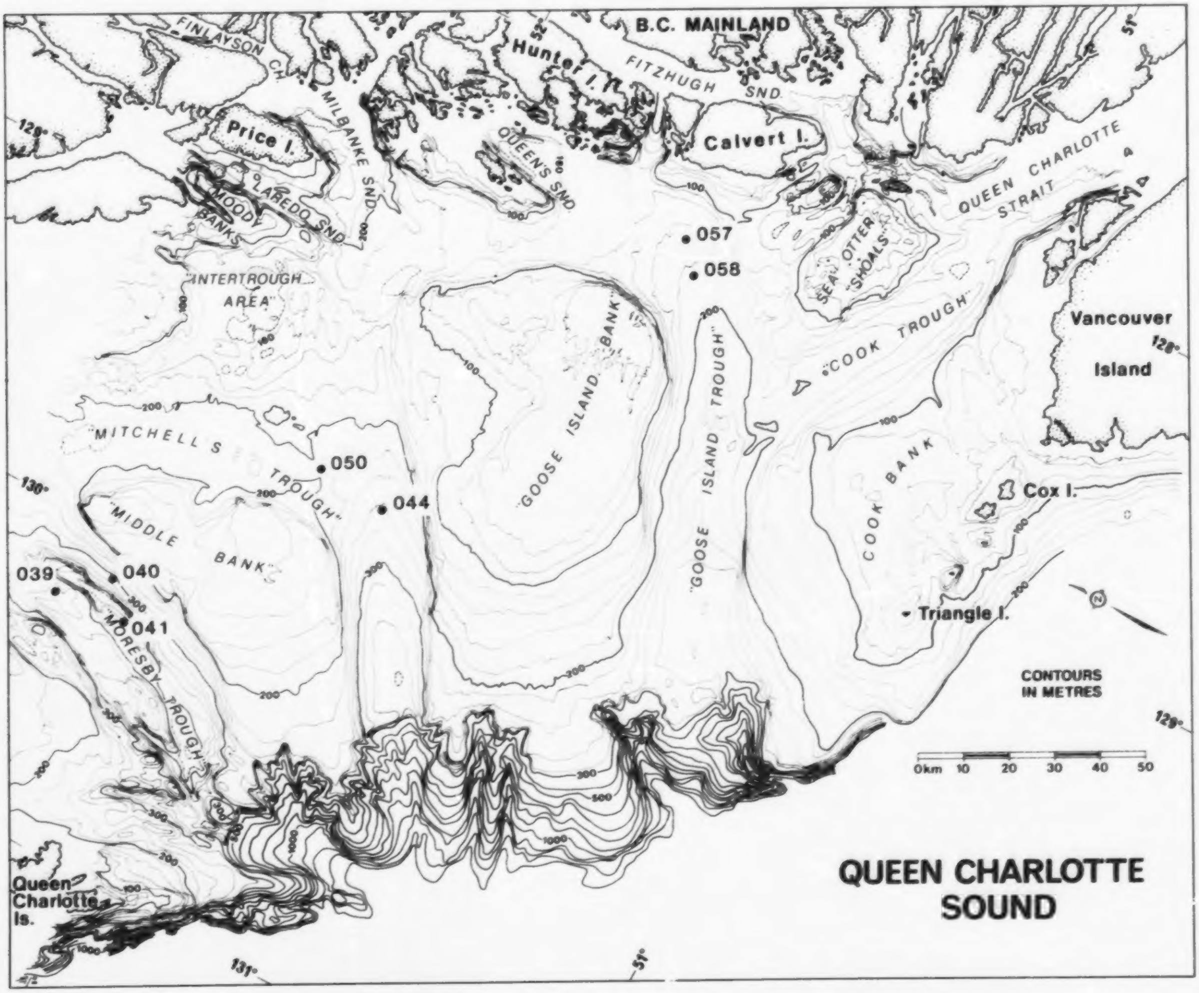
FINLAYSON CH.
B.C. MAINLAND
Hunter I.
FITZHUGH SND.
52°
51°
129°
Price I.
MILBANKE SND.
QUEEN'S SND.
Calvert I.
LAREDO SND
MOODY BANKS
"INTERTROUGH AREA"
• 057
• 058
SEA OTTER SHOALS
QUEEN CHARLOTTE STRAIT
"COOK TROUGH"
Vancouver Island
128°
GOOSE ISLAND BANK
GOOSE ISLAND TROUGH
"MITCHELL'S TROUGH"
• 050
• 044
130°
"MIDDLE BANK"
039
040
041
MORESBY TROUGH
COOK BANK
Cox I.
Triangle I.
CONTOURS IN METRES
0km 10 20 30 40 50
100
200
300
500
1000
QUEEN CHARLOTTE SOUND
Queen Charlotte Is.
131°

Figure 1. Location of piston core sites in Queen Charlotte Sound.

Table 1. Location of piston core sites

CORE	LOCATION	LATITUDE	LONGITUDE
END88B-039	Moresby Trough	52°18.89′N	130°16.47′W
END88B-040	Moresby Trough	52°13.80′N	130°08.85′W
END88B-041	Moresby Trough	52°10.03′N	130°16.29′W
END88B-044	Mitchell's Trough	51°50.32′N	129°35.10′W
END88B-050	Mitchell's Trough	51°58.79′N	129°31.49′W
END88B-057	Goose Is. Trough	51°33.42′N	128°22.34′W
END88B-058	Goose Is. Trough	51°30.58′N	128°28.96′W

Samples were obtained with a gravity piston corer in 3.05 m liner sections of 9.9 cm I.D. which were subsequently cut into 1 m sections. Shipboard operations were limited to torvane measurements on core ends as well as the collection of water content and gas samples from the cutting shoe. The 1 m core sections were then capped, waxed, and refrigerated. The cores were later placed in foam lined core boxes for transportation to the University of British Columbia where they were stored in a high humidity environment until testing. A selection of round subsamples in 20 cm lengths were taken from the END88B cores where no visible evidence of disturbance was seen. These short core lengths were waxed and stored in sea water for possible future consolidation and triaxial testing.

All core sections not retained as subsamples for future testing were subsequently split and laboratory vane shear measurements of peak and residual undrained shear strengths were taken every 10 cm where appropriate. A manually operated Farnell vane shear device was used with a 12.7 x 12.7 mm vane, at a rotation rate of 24°/minute. Peak shear strengths were determined by inserting the vane into the split core and rotating it at constant rate until a maximum spring deflection was surpassed. Next, the vane was rotated through several full rotations in order to remould the sediment and the test was repeated to determine the residual shear strength. No significant difference was observed between residual shear strengths of hand-remoulded and vane-remoulded sediment. Sensitivities were calculated as the ratio of peak to residual vane shear strength.

Water content samples were obtained every 10 cm between vane measurements. All water contents are based on per cent dry weight but were not corrected for salt content because pore water chemistry analyses were not available at time of writing. Atterberg limits (ASTM Standards D423 and D424) were determined on samples taken at intervals sufficient to characterize each distinct unit. Sea water was used in Atterberg limit determinations in order to approximate the pore water chemistry of the sediments.

Grain size analyses were not done at this preliminary stage of the study as the main concern was to determine water contents and shear strengths before cores were significantly altered. However, the core sections have been saved in order to allow for grain size analyses in the future. Bulk densities were the final measurements made.

RESULTS

Three piston cores were recovered from Moresby Trough. The first core, END88B-039, was obtained on a terrace to the west of the trough axis. The entire 7.6 m core length consisted of an olive-green organic clay-silt (Fig. 2). Water contents decreased uniformly from over 90% at the top of the core to about 55% at a depth of 4.0 m. The corresponding peak vane shear strengths over this depth range increased gradually downcore. Below 4 m, the water contents increased while the peak shear strengths decreased somewhat with depth. The residual shear strengths varied in roughly the same fashion as the peak shear strengths, resulting in a sensitivity profile which is relatively constant with an average sensitivity of about 7. Plastic limits (P.L.) showed a consistent value of 30% although variation of liquid limits (L.L.) results in plasticity index (P.I.) values ranging from 28-41%. In all cases, the natural water content was equal to or greater than the L.L. of the sediment. Bulk densities ranged from 1.50 to 1.71 g/cc.

The second Moresby Trough core, END88B-040, was obtained on the eastern trough slope. The core consisted of a 0.6 m thick olive-green clayey silt which overlies a grey silt extending to the bottom of the 4.6 m long core (Fig. 3). A 0.3 m thick grey silt is shown on Figure 3 at the top of the core but its actual existence is not certain as this short section may have been mis-identified on retrieval. The water content of the grey silt was quite low and uniform with depth with an average of about 27%. The olive-green clayey silt had an average water content of 37%. Peak shear strengths appeared quite variable in core END88B-040 but nevertheless generally increased slightly with depth. The residual shear strengths, on the other hand, increased uniformly with depth. Sensitivity, on the average, remains constant with depth with a value of 9. Atterberg limits could not be determined for this core because the plasticity of the grey silt was very low to non-existent. The bulk density of the grey silt near the bottom of the core was 2.00 g/cc.

The third Moresby Trough core, END88B-041, was obtained from the recent sediments at the centre of the trough. The core is comprised entirely of an organic olive-green clay-silt with a bulk density of 1.5 g/cc (Fig. 4). On recovery of the core, closely spaced gas cracks were visible below 4.0 m. Water content decreased uniformly from about 120% at the top of the core to 74% at the bottom. The peak shear strengths were fairly constant from 0-2 m where they were generally less than 7 kPa. Below this, peak shear strength increased irregularly with depth, as did the residual strength profile. As a result, below 2.0 m sensitivity was relatively constant with a value of about 5. Above 2.0 m, the very low residual strengths shown by the sediment yield high sensitivities which are quite variable. The limited accuracy to which the laboratory vane can measure such low residual strengths contributed to the large variability. Water contents are close to the L.L. values with P.I. values ranging from 34-46%.

Two cores were recovered from Mitchell's Trough[1]. The first core, END88B-044 showed a uniformly increasing peak shear strength profile with depth (Fig. 5), although the values are somewhat variable from the layered sediment below 2.0 m. Water contents exhibited significant variation with depth and no consistent variation is evident except at 2.0 m where there was a sharp increase in water content and perhaps below 4.0 m where water contents increased. The zone of higher water contents between 2.0 and 4.0 m corresponds to the section where there are more silt-sand

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[1] The geographic names Mitchell's Trough and Goose Island Trough are informal and have not been approved by the Advisory Committee on Undersea Feature Names.

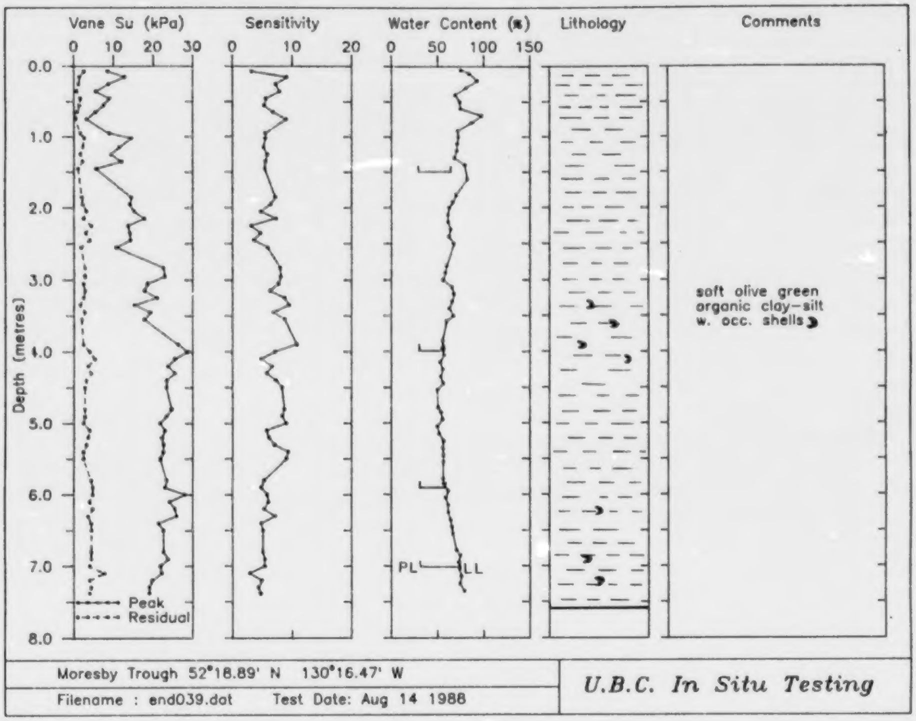

Figure 2. Summary of properties, core END88B-039.

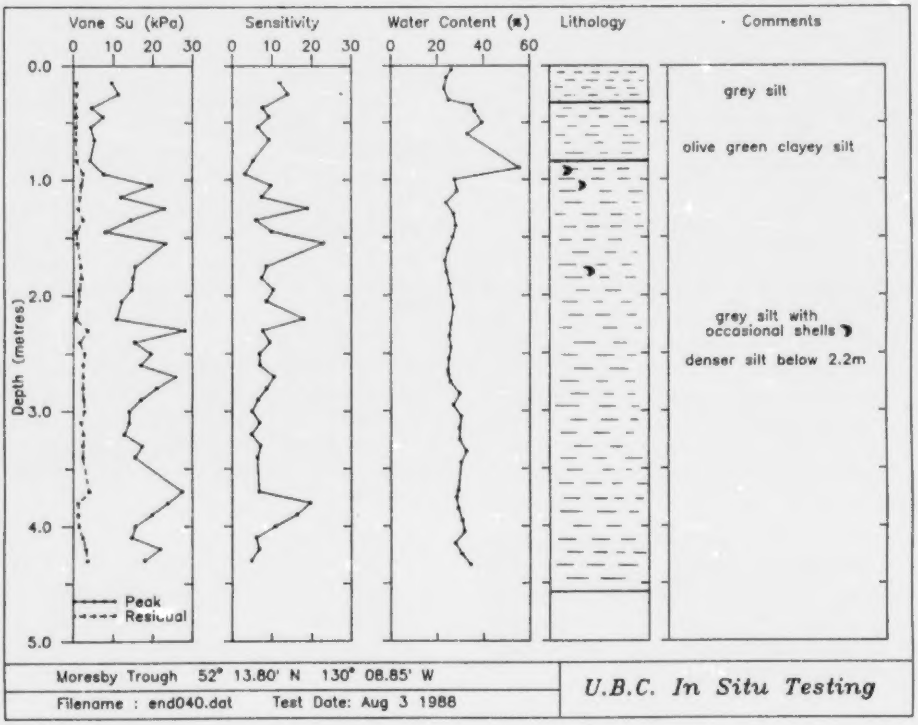

Figure 3. Summary of properties, core END88B-040.

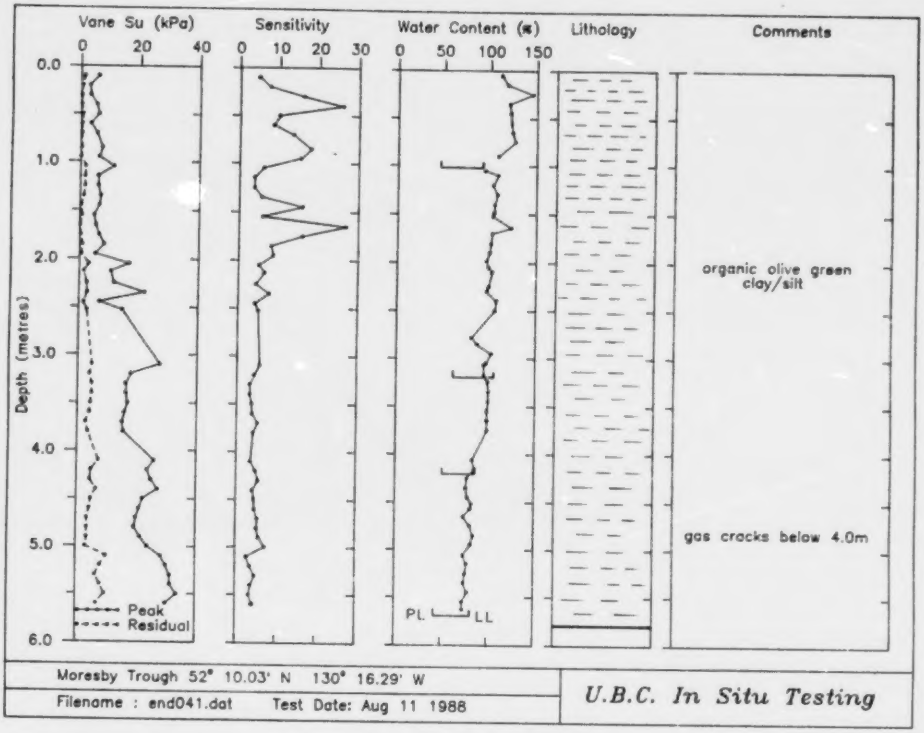

Figure 4. Summary of properties, core END88B-041.

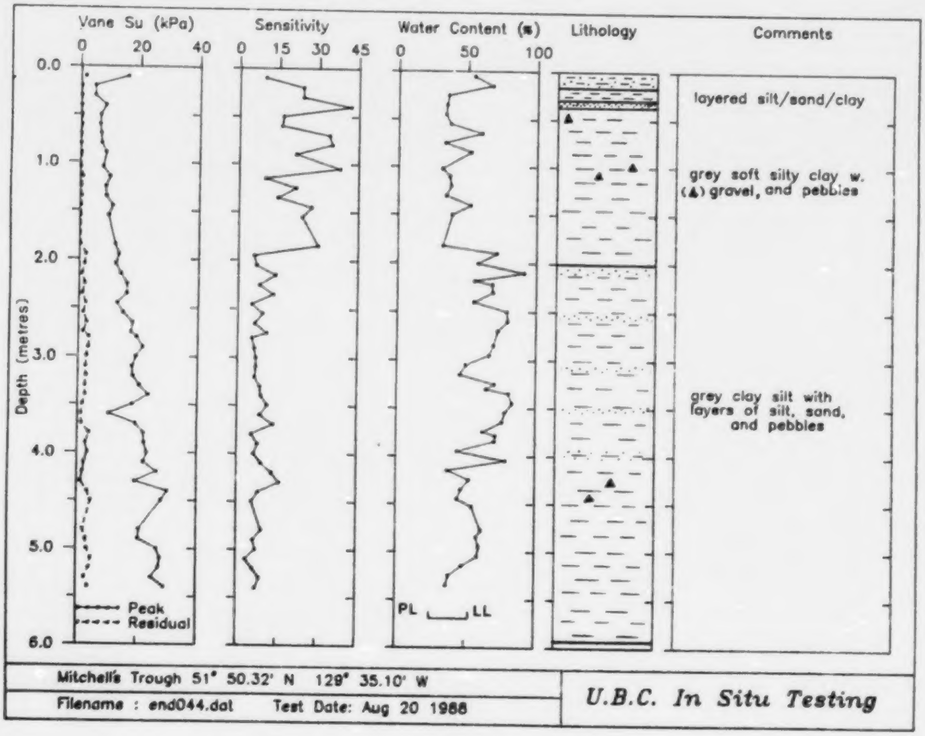

Figure 5. Summary of properties, core END88B-044.

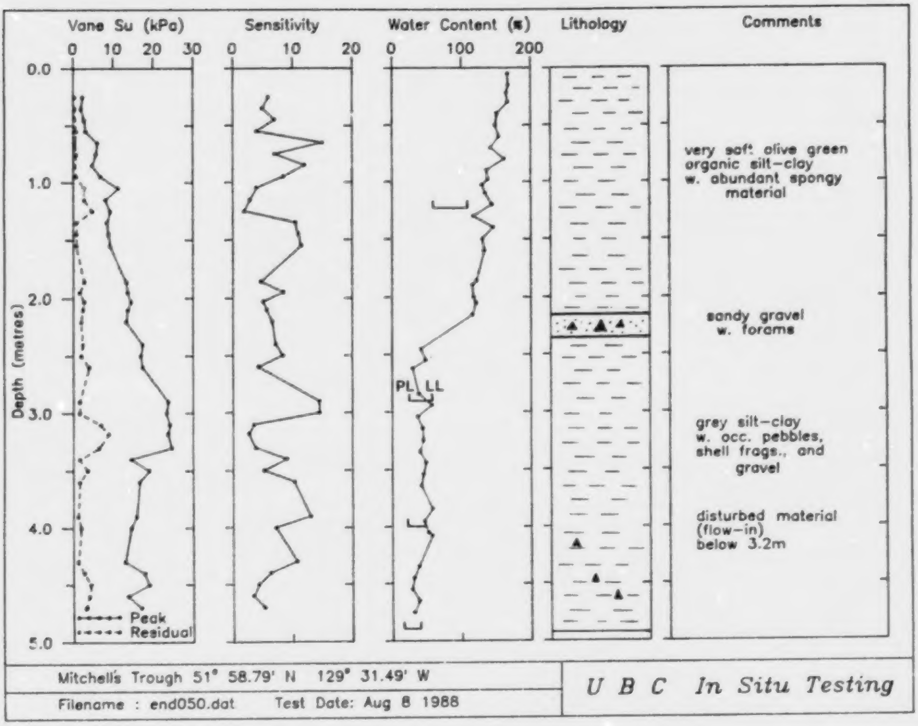

Figure 6. Summary of properties, core END88B-050.

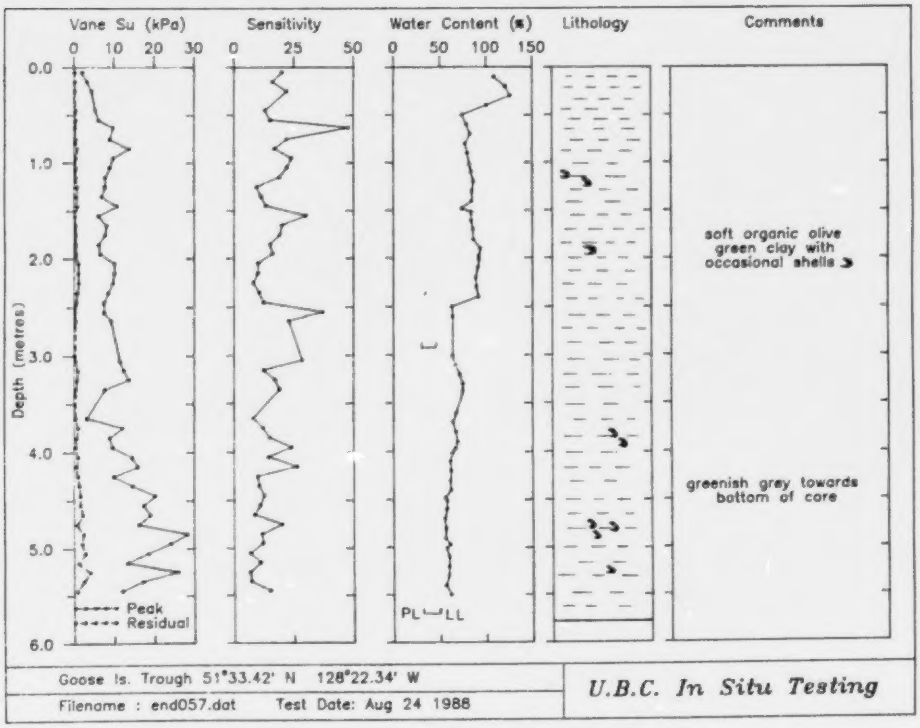

Figure 7. Summary of properties, core END88B-057.

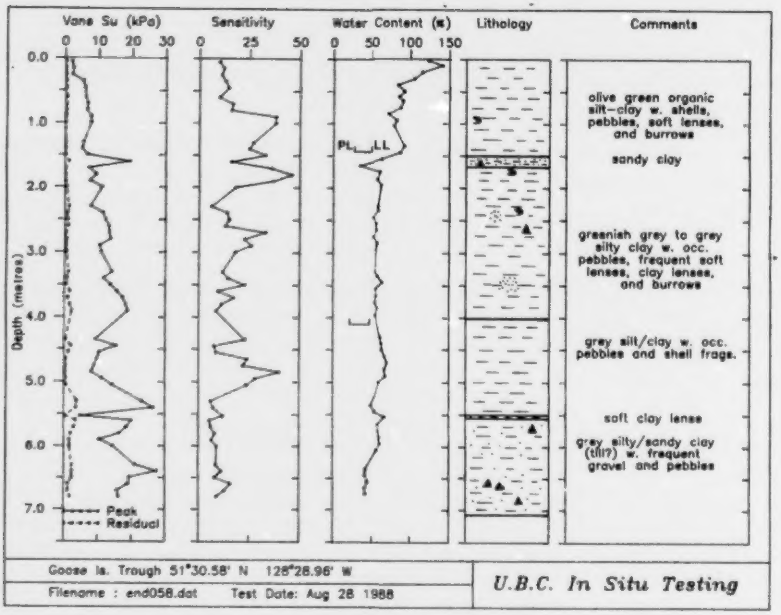

Figure 8. Summary of properties, core END88B-058.

Table 2. Torvane shear strengths of core section ends

CORE	DEPTH (m)	SHEAR STRENGTH (kg/cmi2) SHIP	LAB
END88B-039	2.80	0.28	0.11
	3.80	0.14	0.20
	4.76		0.18
	5.76	0.28	0.11
END88B-040	3.68	0.20	0.13
END88B-041	2.00	0.10	0.04
	5.04	0.23	0.21
END88B-044	1.00	0.13	0.06
	1.80	0.18	0.13
	2.20		0.13
	2.77	0.16	0.14
	3.77	0.26	0.25
	4.77	0.29	0.20
END88B-057	2.00	0.09	0.02
	2.86	0.16	0.15
	3.99		0.08
	4.99	0.24	0.24
END88B-058	2.27	0.07	0.06
	3.37	0.20	0.09
	4.21	0.15	0.14
	5.28	0.25	0.15
	6.28	0.20	0.09

layers. Here again, the very low values of residual strength above 2.0 m result in high and variable sensitivities. Below 2.0 m sensitivity was less variable, lower, and is roughly constant with depth. Atterberg limits at the bottom of the core gave a P.L. of 23% and a P.I. of 27%. Bulk densities of 1.7 g/cc were determined at three depths.

The second Mitchell's Trough core, END88B-050, consisted of 2.2 m of organic silt-clay which overlies a thin sandy gravel (Fig. 6). A grey silt-clay which extended to the bottom of the core underlay the sandy gravel at a sharp contact. Water contents steadily decreased from the top of the core to a depth of 2.2 m where water content dropped sharply at the upper contact of the grey silt clay. For the remaining depth of core, the water contents were roughly constant. The water contents above 2.2 m were significantly greater than the L.L. determined for the sediment. The P.L., L.L., and P.I. values for the grey silt-clay are much lower than those for the overlying organic silt-clay and decreased with depth. Also, the bulk density of the organic silt-clay is only 1.34 g/cc while that of the grey silt-clay is approximately 1.9 g/cc. The peak undrained shear strengths increase uniformly to a depth of 3.3 m where they sharply decrease. Disturbed 'flow-in' sediment below 3.2 m in the core is the cause of the lower shear strengths. The shapes of the peak and residual strength profiles are quite similar, resulting in a sensitivity profile which, although somewhat variable, remains essentially constant with depth.

The first of two cores recovered from Goose Island Trough, END88B-057, consisted of an organic olive-green clay which graded to a greenish-grey clay towards the bottom of the core (Fig. 7). Peak shear strength values increase downcore but are more variable below 3.2 m. Remoulded strengths are very low and increase only slightly with depth resulting in fairly high, though variable, sensitivities. The water contents below 0.5 m remained constant with depth except at 2.4 m where a 30% drop in the water content was evident. Water contents were well above the L.L. values obtained for the sediment which has a P.I. of 17%. Measured bulk densities fall between 1.6 and 1.7 g/cc.

The second Goose Island Trough core, END88B-058, consisted of an olive-green organic silt-clay overlying various grey silt-clay units (Fig. 8). The peak shear strengths increased downcore but were variable. This may largely reflect lenses and layers of sand and silt within the sediment. Low residual shear strength values throughout most of the core result in fairly high but variable sensitivities except in the grey silty-sandy clay at the bottom of the core which exhibited the highest residual shear strengths. Water contents were highest in the organic silt-clay at the top of the core and decreased slightly with depth in the underlying sediment. The water contents were well above the L.L. values determined for the sediment. Bulk densities are essentially constant downcore with measured values ranging from 1.68 to 1.83 g/cc.

DISCUSSION

Although a site-specific analysis of sediment stability has not been done at this stage of the study, some general inferences can be drawn from the geotechnical results obtained.

Firstly, liquidity index values (representing water contents normalized relative to plasticity) are generally close to or greater than one, suggesting the possibility of highly sensitive sediment. This indication is confirmed on examination of the calculated sensitivity profiles for the core sites. Sensitivities generally fall in the range 5-30 corresponding to a Rosenqvist sensitivity classification (in Mitchell and Houston, 1969) of the order of very sensitive to medium quick clays.

Highly sensitive clays may be of particular concern with respect to slope stability, because many of the slope failures which developed during the 1964 Anchorage, Alaska, earthquake involved failures through clay of high sensitivity. Furthermore, stress-strain relationships are related to sensitivity in that sensitive clays generally exhibit low values of strain at failure (i.e., sensitive clays tend to be brittle and can lead to progressive failures).

However, slope angles are no greater than only several degrees for all core sites. When this is taken into consideration along with the peak shear strength values obtained it is apparent that slopes probably are statically stable.

Furthermore, the peak shear strengths are likely underestimated in light of core disturbance effects. A rough indication of the degree of such handling and transportation disturbance effects can be drawn from comparisons of torvane measurements taken on core ends immediately after sampling and those taken in the laboratory at a later date. Such a comparison (Table 2) indicates an average peak shear strength reduction of 30%. This reduction is in addition to any shear strength reduction as a result of the sampling operation. Thus, the in situ peak shear strengths may be significantly higher than those portrayed in the shear strength profiles of Figures 2 to 8. As a result, even the relatively high sensitivities calculated for each profile tend to underestimate the actual sensitivity values.

With respect to fine grained sediment, clay or silt with low plasticity index has been found to be just as vulnerable to liquefaction as are loose clean sands (Ishihara et al., 1980). This is particularly relevant to core END88B-040 which was recovered from the slope of Mitchell's Trough and consists almost entirely of a low plasticity silt. Indeed, attempts to quantify the plasticity of this sediment by means of P.I. determinations proved to be unsuccessful for such a low plasticity material. In addition, at least some of the sediment from Mitchell's Trough and Goose Island Trough is classified as a low plasticity sediment according to the Unified Soil Classification System. Of course, further testing would be required in order to quantify the dynamic behaviour of these sediments.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Most slopes are likely statically stable due to low slope angles and sufficient peak undrained shear strengths. Further, at least some of the sediment in all troughs sampled has a low plasticity index, suggesting possible liquefaction susceptibility to dynamic wave or earthquake loading.

The results from this preliminary study form a basis for further investigations of sediment instability in Queen Charlotte Sound. In order to characterize the sediments already sampled, grain size determinations as well as consolidation testing to determine stress history and compressibility are required. In addition, static triaxial tests are required for the silt to determine Mohr-Coulomb effective strength parameters where site specific slope stability analysis is desired. Cyclic triaxial testing will be necessary for the analysis of dynamic stability under cyclic earthquake or wave loading. Selected subsamples from the recovered cores have been retained and stored in order that such testing mentioned above may be performed in the future.

It is also important to integrate and extend the geotechnical results with seismic interpretations and geological evidence in order to obtain a better understanding of the geotechnical sediment characteristics within Queen Charlotte Sound.

Lastly, locations along the relatively steep slopes of Mitchell's Trough where obvious evidence of slope instability exists (Luternauer and Conway, 1986) were not geotechnically sampled. These slopes are draped with sands which were considered to be unsuitable for piston coring. Unfortunately, these slopes are also of greatest interest in terms of stability analysis as a result of the failures along these slopes. Future emphasis should be put on obtaining geotechnical information in this critical area. An in situ testing program with at least cone penetration testing, while quite costly, is necessary to assess the stability of these sandy slopes since sampling is inappropriate in cohesionless sediments.

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